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ACCELERATED MISSION TEST OF A TF41 WITH AIRCOOLED SECOND STAGE --ETC(U)
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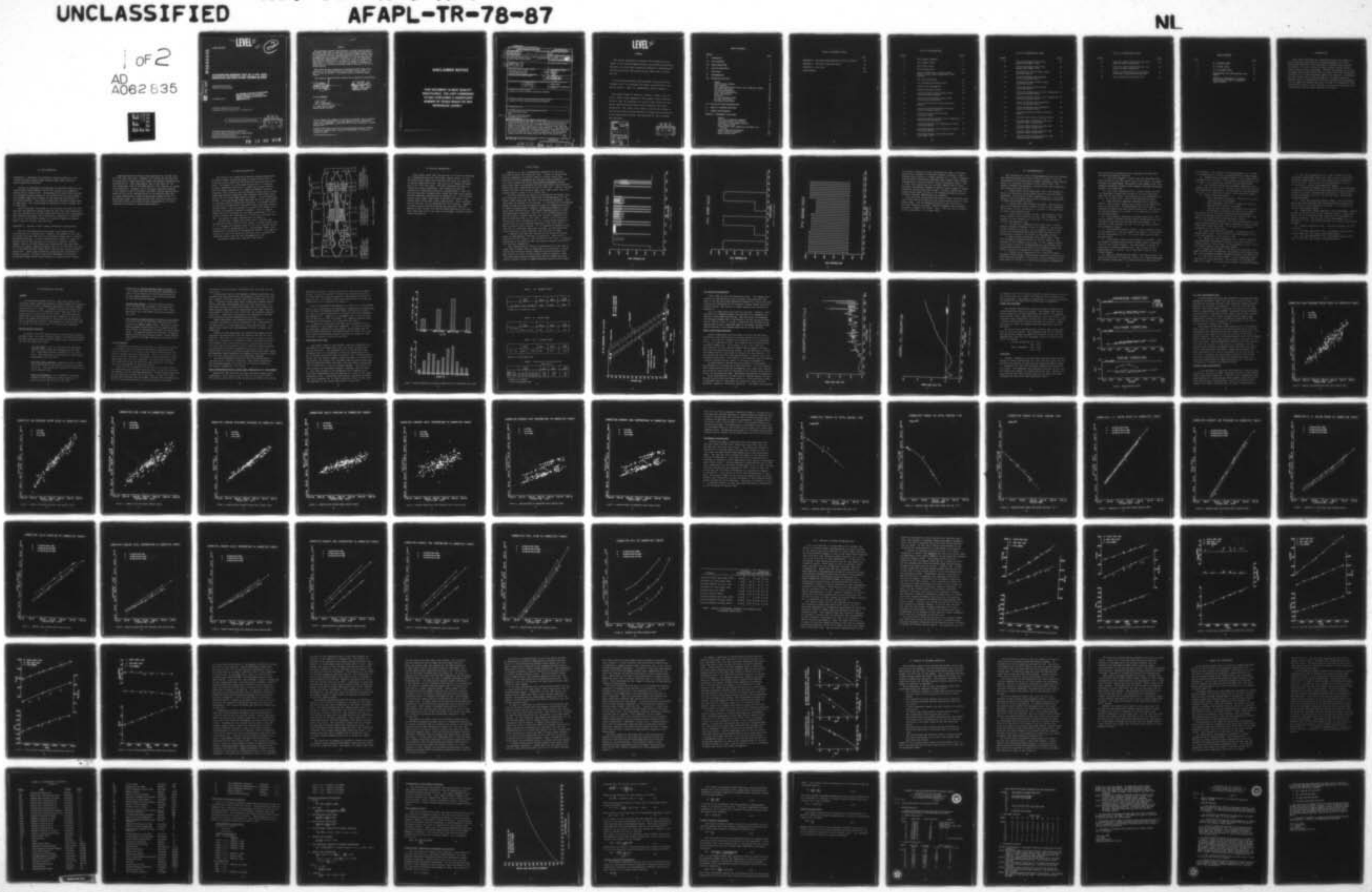

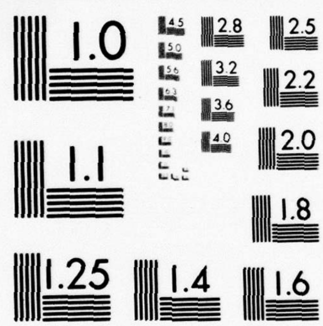

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LEVEL II

AFAPL-TR-78-87

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ACCELERATED MISSION TEST OF A TF41 WITH AIRCOOLED SECOND STAGE TURBINE BLADES

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TECHNICAL REPORT AFAPL-TR-78-87
Final Report for Period 10 August 1977 – 26 October 1977

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An accelerated mission test (AMT) of a TF41 was conducted in the Air Force Aero Propulsion Laboratory's "3" stand sea level engine test facility between 10 August 1977 and 26 October 1977. The primary objective of the test was to evaluate the structural reliability of a set of aircooled second stage high pressure turbine blades under realistic usage conditions. A two hundred sixty three hour test program was initially planned but only one hundred sixty hours were actually completed due to a variety of problems. A post-test teardown inspection revealed that six of the new aircooled blades had indications of fatigue cracks near the leading edge of the blade on the suction side.

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LEVEL II

FOREWORD

This report describes an in-house test conducted by personnel of the Turbine Engine Division and Technical Facilities Division, Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio, under project 3066, Task 12, Work Unit 36.

The work reported herein was performed during the period 10 August 1977 to 26 October 1977 under the direction of the author, Robert J. May, Jr. (AFAPL/TBA), project engineer.

The author wishes to thank Mr. Richard G. Homer, test operator, Messers Paul Haggedorn, Nick Goggin, Robert Whitlock, who were test cell observers at various times during the test and Mr. Mark Reitz, who aided in data reduction and report preparation. The author also wishes to express his thanks to the Detroit Diesel Allison Division of General Motors, especially Mr. Darwin Hoose and Mr. Gary Williams for their patience and assistance.

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I INTRODUCTION

This report describes an accelerated mission test (AMT) of a Detroit Diesel Allison TF41-A-1 (turbofan engine), S/N 141677. The primary objective of the test was to evaluate the structural reliability of a set of aircooled high pressure turbine blades under realistic usage conditions. The test was carried out between 10 August 1977 and 26 October 1977 in the Air Force Aero Propulsion Laboratory's "3" stand sea-level engine test facility. Two hundred and sixty-three hours of AMT Testing were initially scheduled. However, due to a combination of factors, including the requirement for the engine for another AMT test, its high oil consumption, and a structural failure in the facility, the test was terminated after 160 AMT hours and the engine returned to Allison.

II TEST OBJECTIVES

OBJECTIVE 1: Establish the durability characteristics of a set of TF41 aircooled second stage turbine blades under realistic engine operating conditions.

Allison is proposing to incorporate an aircooled blade into the second stage turbine (HPT-2) of the TF41 as part of a program to extend the hot section life. The present HPT-2 blades have suffered from thermal fatigue failures of the airfoil and low cycle fatigue (or possible high cycle fatigue) in the blade and disk serration, (Fir Tree Dovetail). The current blades have estimated design lives of 1000 hours. The cooled blade is estimated to have a design life of 2000 hours.

One of the major criticisms of the 1973 Audit and both the 1974 and 1975 TF41 Executive Review Groups was that the lives (especially low cycle fatigue life) of many engine parts are not well established. This objective addresses this criticism by attempting to establish the life of the new HPT-2 blades in a realistic engine environment before they are retrofit into the fleet.

OBJECTIVE 2: Document overall engine performance deterioration.

The 1974 TF41 Executive Review Group listed engine thrust deterioration as a problem area. However, the engines in the field are seeing less than 200 hours of use before overhaul due to assorted durability problems. In this relatively short amount of time, the engines have not deteriorated to the point of causing a problem. However, many of the CIP objectives, including the aircooled HPT-2 blades, are aimed at improving engine life to the point where the TF41 is a "firm 1000 hour MOT engine with a 500 hour hot section periodic inspection". Under these conditions, deterioration is expected to become a problem. The most recent TF41 Management Review Group established engine thrust deterioration as a prime area of concern.

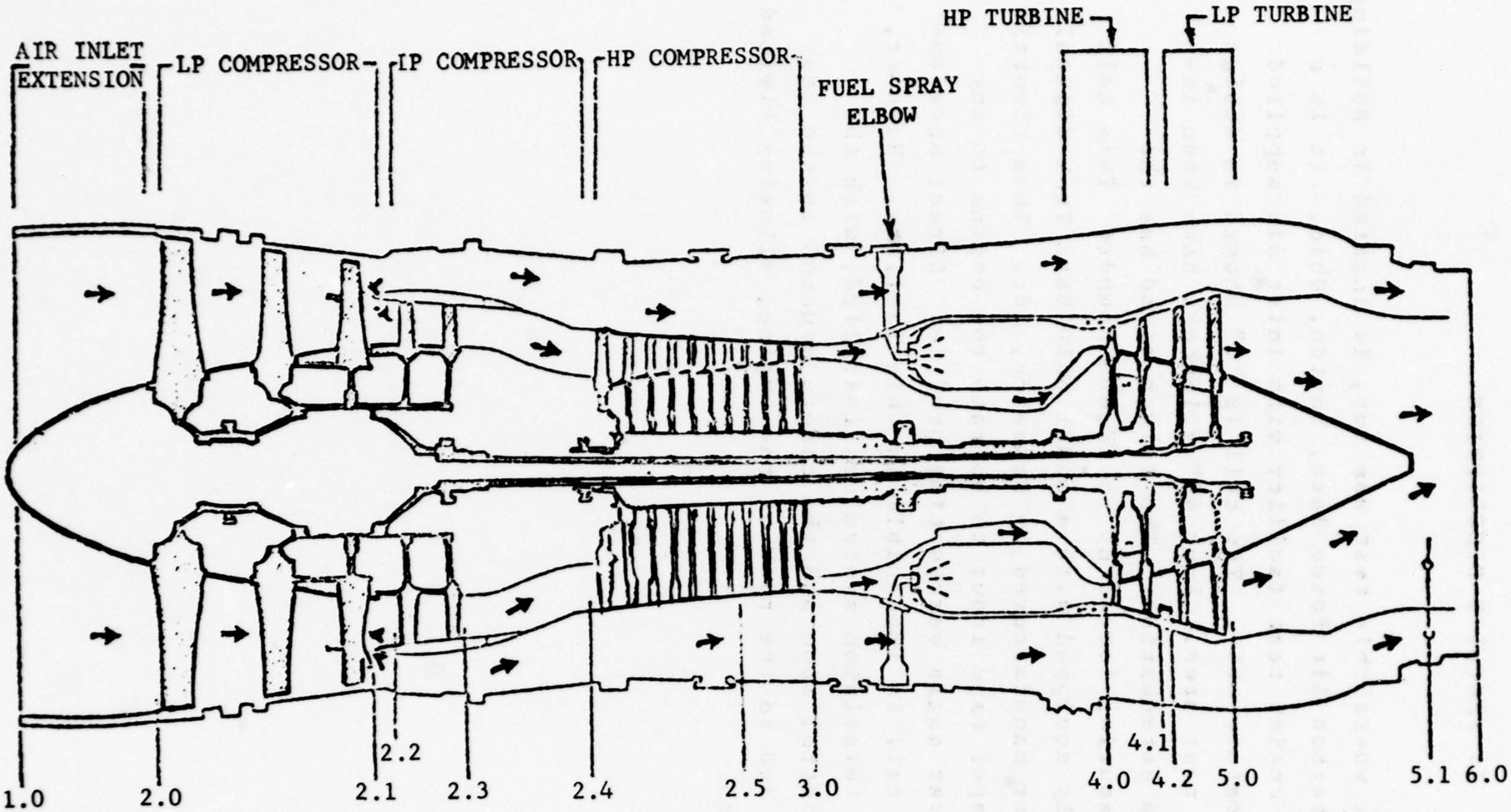
Some deterioration data has been generated by the AEDC test of a TF41 this past year. However, this engine did not have the aircooled HPT-2 blades which may impact the engine's deterioration characteristics. More importantly, due to the nature of the test objectives, most of the AEDC engine's test time was at steady state conditions. However, due to the many transients imposed on the engine in the A7 Aircraft, the AEDC's engine deterioration would not be totally representative of the deterioration that an engine would exhibit after an equivalent number of hours in operational usage. The deterioration data from this type of accelerated mission test should be more representative of field usage and its effects on engine deterioration.

III ENGINE DESCRIPTION

The TF41-A-1 is a mixed flow turbofan engine manufactured by Detroit Diesel Allison Division of General Motors and is currently used to power the Air Force's A7-D ground attack aircraft. The engine is a twin spool design with a 3 stage low pressure compressor driven by a 2 stage low pressure turbine. The core engine consists of a 2 stage intermediate pressure compressor also driven by the low pressure turbine and an eleven stage high pressure compressor with variable inlet guide vanes driven by a two stage high pressure turbine. In the production version, first and second stage vanes and the first stage blades of the high pressure turbine are aircooled. The engine tested was specially equipped with aircooled second stage high pressure turbine blades. The main burner is an axial flow design incorporating ten cannular combustion chambers. The core engine exhaust gas and the bypass air are mixed downstream of the low pressure turbine and exhausted out a fixed area convergent nozzle. The engine is shown schematically in Figure 1.

The TF41 has a design (sea level static, standard day, intermediate power) airflow of 261 lb/sec, a design bypass ratio of .7, a design fan pressure ratio of 2.45 and a design overall pressure ratio of approximately 22. The maximum turbine inlet temperature is estimated at approximately 2625^{o}R. The engine is rated at 14,500 lb of thrust at sea level static standard day conditions with a specific fuel consumption of .654.

The engine tested was a TF41-A-1, S/N 141677.



1.0 Engine Inlet
2.0 LP Compressor Inlet
2.1 Bypass Duct Inlet
2.2 IP Compressor Inlet
2.3 IP Compressor Outlet
2.4 HP Compressor Inlet
2.5 Seventh Stage Bleed Outlet
3.0 HP Compressor Outlet
4.0 HP Turbine Inlet
4.1 HP Turbine Outlet
4.2 LP Turbine Inlet
5.0 LP Turbine Outlet
5.1 Measured Gas Pressure and Temperature Station
6.0 Engine Outlet

FIGURE 1 - TF41 ENGINE SCHEMATIC

IV FACILITY DESCRIPTION

Three stand, where this test was run, is located in Building 71 at Wright-Patterson Air Force Base, Dayton, Ohio. It is a sea level static engine test facility with inlet air supplied at ambient temperature only. The cell is "U" shaped in design with a 20' x 20' test area. Four 48" silencers have been installed for sound attenuation. The thrust stand has the capability of measuring forces up to 18,000 pounds. This cell has been specially equipped with a model 6610 Data Trak digital process programmer manufactured by Research, Inc. This throttle control uses a paper tape input to operate the engine to any desired power lever angle versus time profile. Direct observation of the test cell is impossible in this facility. However, a closed circuit television system was installed, with the monitor in the control room and the camera mounted in the test cell, well above and to the rear of the engine, allowing limited visual observation.

V TEST CYCLES

Figures 2, 3, and 4, graphically represent the throttle transient profiles run during the test. Percent of design high pressure compressor rotational speed is plotted versus time. These cycles were programmed into the Data Trak, automatic throttle control making use of the high pressure compressor speed, power lever angle relationship for this engine which was generated during the power calibration portion of this test. This is required because the Data Trak controls power lever angle rather than compressor speed in order to be a closed loop.

The cycle depicted in Figure 2 is designated the Flight cycle (also referred to as an "A" cycle) and is representative of the actual flight usage that the TF41's are seeing in the field. This cycle lasts 43 minutes and 29 seconds. It consists of a considerable number of engine accels and decels as well as a significant amount of time at maximum power. Figure 3, graphically depicts a Start cycle (also referred to as a "B" cycle) representative of flight line maintenance operation. Each "B" cycle includes 10 minutes and 30 seconds of engine operation and contains 3 engine starts and the remaining time at idle power. Figure 4, is a so-called Ground cycle (also referred to as a "C" cycle) which reproduces typical test cell and trim pad operation. This cycle lasts 2 hours 6 minutes and 15 seconds. It is composed of several accels from idle to relatively high power settings, followed by steady state operation at this condition, and the decel to idle.

A complete TF41 AMT test consists of 15+ blocks of testing which is approximately 263 hours of operation. Each block is made up of 20 "A" cycles, 4 "B" cycles and 1 "C" cycle. A complete tabulation of the steps in each cycle may be found at the back of the test plan, Appendix D.

This combination of cycles is representative of the type of usage that a typical TF41 is subjected to in the field. A joint Allison and Air Force project compiled and analyzed data from many sources in order to derive these throttle profiles. Navy "Inflight Engine Condition Monitoring System" (IECMS) Data was used to provide records of engine histories during actual flight.

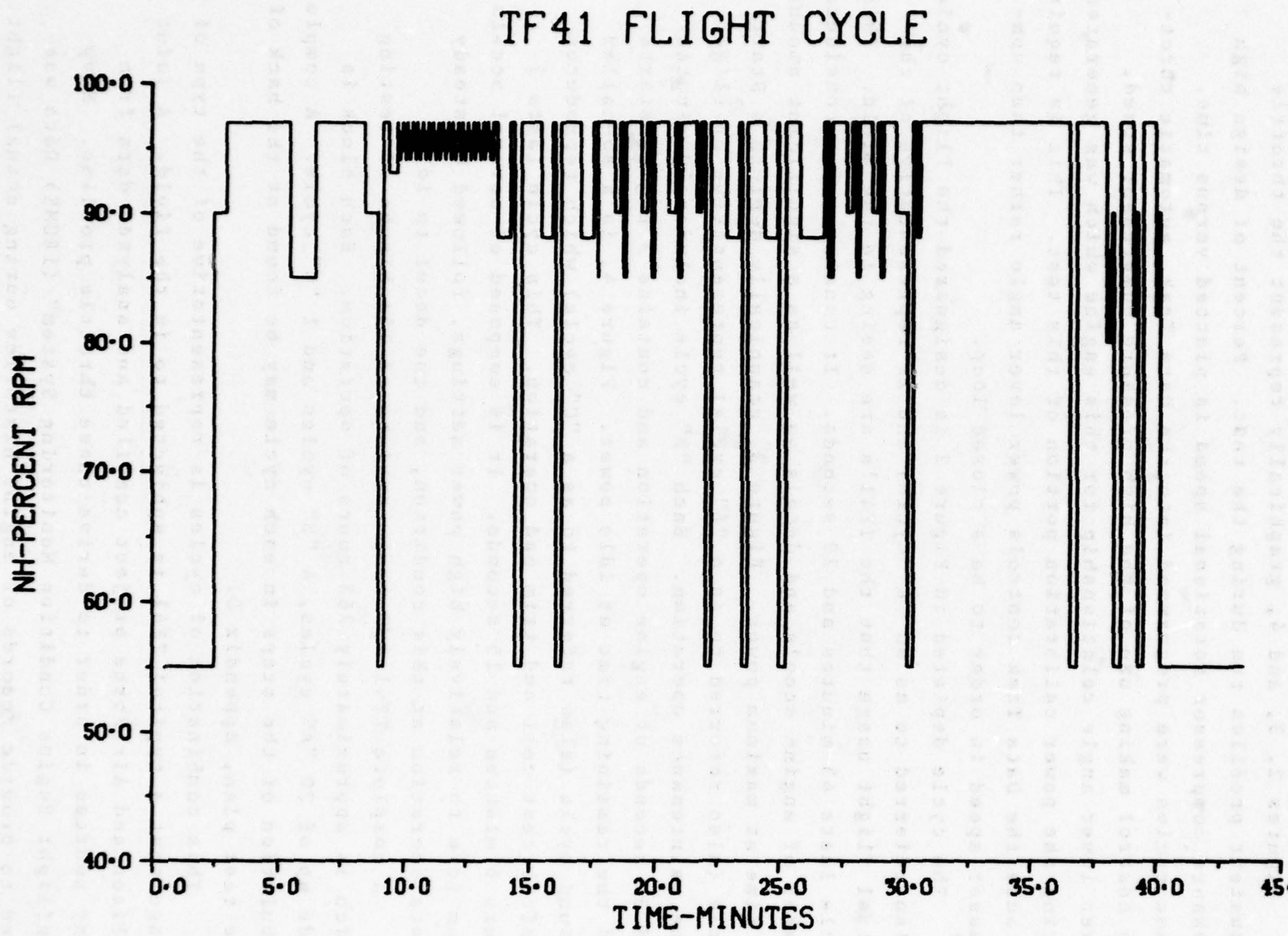


FIGURE 2 - TF41 FLIGHT CYCLE

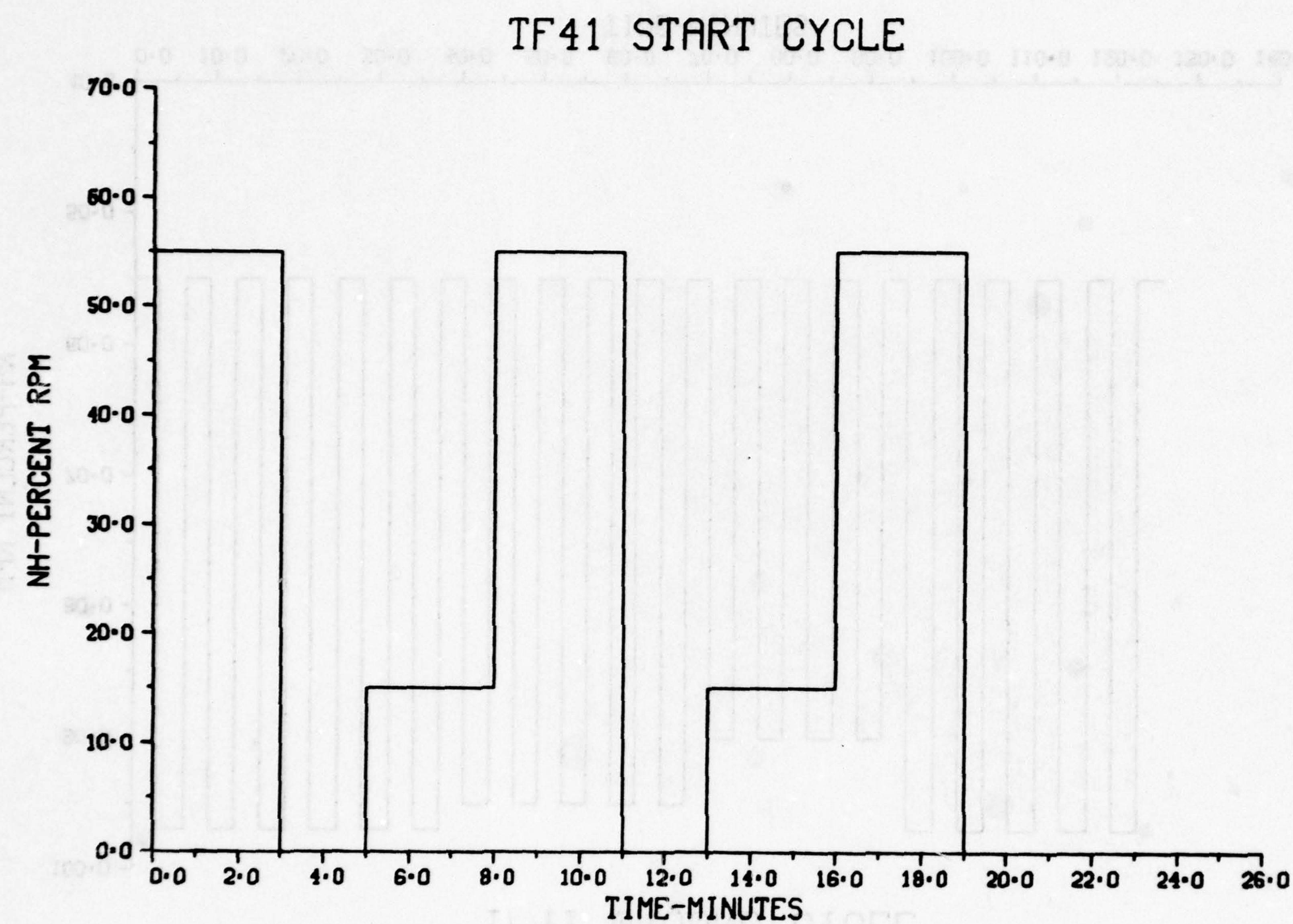


FIGURE 3 - TF41 START CYCLE

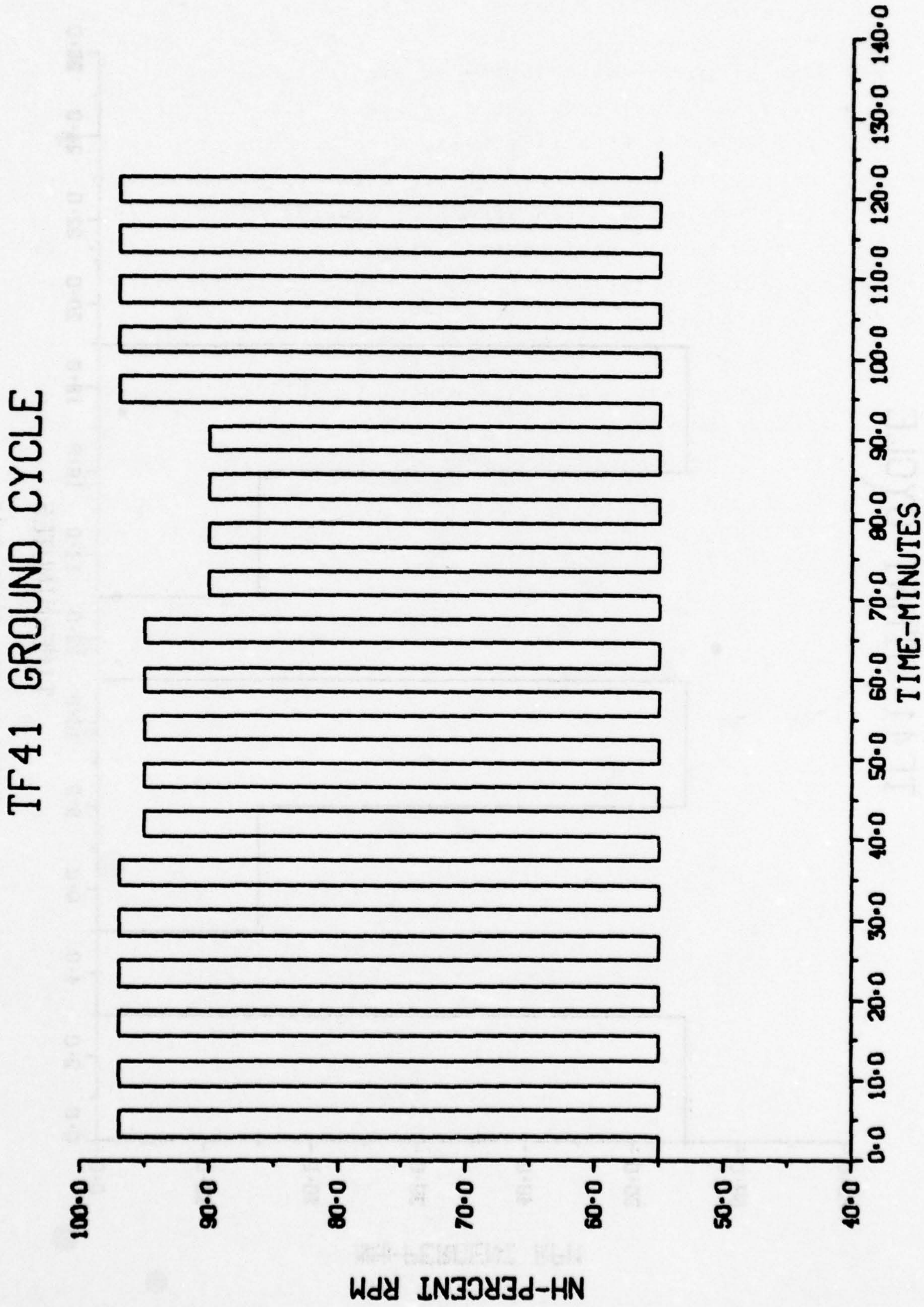


FIGURE 4 - TF41 GROUND CYCLE

An extensive program of pilot interviews was used to determine mission mix, estimates of throttle movement frequency, time at maximum power, effects of flight position (i.e., lead or wingman), mission profile definition (altitude, Mach number, time, weight, configuration), and the effects of pilot experience level. Also a flight test program was run at AFFTC, Edwards AFB CA using specially instrumented engines to define typical ranges of engine parameters during operational flight. Finally, engine data recorded during flight as part of the "Engine/Airframe Structural Integrity Program" (ENSIP/ASIP) was assessed.

All this data was analyzed and used to define the three real time cycles and the proper mix that would directly relate to real engine usage. The non-damaging portions of the cycles (i.e., low power operation and small throttle changes) were eliminated in order to compact the cycles. Thus, 1 AMT test hour is approximately equivalent to 1.9 flight hours.

VI INSTRUMENTATION

The following is a list of instrumentation that was available and operative during this test of TF41 S/N 141677. All the instrumentation was displayed on gauges, manometer tubes, digital meters, or continuous recorders in the control room. The various readings were manually recorded by the test technicians when required during the test.

1. Engine inlet total temperature (°F) - the average of three iron-constantan thermocouples located in the air inlet bellmouth. The accuracy of this reading is $\pm$ 1°F. It is read from a control room gauge and is also continuously recorded on an Offner oscillograph recorder.

2. Engine inlet total pressure (in H2O) - the average of three total pressure probes located in the air inlet bellmouth. The accuracy of this reading is $\pm$ .1 in H2O. It is read from a control room manometer tube.

3. Inlet static pressure (in HG) - the average of three static pressure taps located in the air inlet bellmouth. The accuracy of this reading is $\pm$ .01 in HG. It is read from a control room manometer tube.

4. Low pressure compressor rotor speed (rpm) - from an engine furnished tachometer on the L.P. gearbox. The accuracy of this reading is $\pm$ 20 rpm. It is a digital readout in the control on a Beckman/Berkeley digital EPUT meter and is also continuously recorded on an Offner oscillograph recorder.

5. High pressure compressor rotor speed (rpm) - from a test equipment tachometer mounted on the H.P. gearbox. The accuracy of this reading is $\pm$ 10 rpm. It is a digital readout in the control room on a Beckman/Berkeley digital EPUT meter, continuously recorded on an Offner oscillograph recorder, and read as a percent of design on a control room gauge.

6. Turbine outlet temperature (°F) - from nine engine furnished chromel-alumel thermocouples connected in parallel and electronically averaged. The accuracy of this reading is $\pm$ 4°F. This signal is readout on a control room temperature gauge and is

also recorded continuously on both a Honeywell recorder and an Offner oscillograph recorder.

7. Fuel flow (LB_M/HR) - from a test cell furnished flow meter located in the fuel supply line to the engine. The range of this meter is 0-10,000 LB_m/HR. The accuracy of this reading is $\pm$.5%. This reading is continuously recorded on both a Honeywell and Offner oscillograph recorder in the control room.

8. Fuel inlet temperature (°F) - from a closed-tip type iron-constantan thermocouple located in the test stand fuel line near the flow meter. The accuracy of this measurement is $\pm$ 1°F. It is read from a control room temperature gauge.

9. High pressure compressor discharge static pressure (PSIG) - from a static pressure tap located on the number nine strut in the diffuser. The measurement is from an engine furnished fitting on the fuel control sense line. The accuracy of this measurement is $\pm$ .05 PSI. It is read from a control room pressure gauge.

10. High pressure compressor discharge temperature (°F) - from two engine furnished chromel-alumel thermocouples located in numbers three and nine fuel nozzles and averaged. The accuracy of this reading is $\pm$ 1°F. It is read from a control room temperature gauge.

11. Fuel manifold pressure (PSIG) - from a pressure tap on the fuel manifold on the left side of the engine. The accuracy of this measurement is $\pm$ 1%. It is read from a control room pressure gauge.

12. Low pressure turbine total pressure (in HG ABS) - from nine engine furnished total pressure probes spaced circumferentially in the turbine exhaust. The measurement is picked up from the P5.1 pressure manifold tap. The accuracy of this measurement is $\pm$ .1 IN HG. It is read from a control room pressure gauge.

13. Main oil pressure drop (ΔP) (PSID) - from high pressure fitting on oil filter and low pressure fitting on oil cooler inlet flange. This measures engine main oil pressure minus internal gearbox

oil pressure. The accuracy of this measurement is ± .5 PSID. It is displayed on a control room differential pressure gauge.

14. Engine main oil pressure (PSIG) - from a high pressure fitting on the oil filter. The accuracy of the measurement is ± .5 PSI. It is read from a control room pressure gauge.

15. Low pressure cooling air discharge temperature (°F) - taken at the jack on the L.P. cooling air duct fitting using an iron-constantan thermocouple. The accuracy of this measurement is ± 1°F. It is read from a control room temperature gauge.

16. Engine vibrations (mils)

- Front compressor (vertical) - mounted on the front flange on top of the engine.
- Rear compressor (vertical) - mounted on the fuel manifold boss ontop of the engine.
- Turbine (near vertical) - mounted on the low pressure turbine oil tube boss on the bottom of the engine.

The vibrations are read from Consolidated Electrodynamics type 1-117 vibration meters located in the control room. The meters are equipped with 30 HZ high bypass filters.

17. IGV position (degrees) - an angle probe mounted on the engine airflow regulator and measures regulator travel in terms of HP inlet guide vane angle. It is read out on a digital multimeter in the control room.

18. Power lever position (degrees) - measures the total cambox lever travel. The accuracy of this measurement is ± 1°. It is read digitally in the control room.

19. Engine oil inlet temperature (°F) - from a closed tip iron-constantan thermocouple located in the tube to the L.P. turbine bearing. The accuracy of this reading is ± 1°F. It is read from a control room temperature gauge.

20. Engine thrust (LB_F) - from load cell deflection. The range of the load cell is 0-18,000 LBS. The accuracy of this reading is ± 50 LBS. It is continuously recorded on a Honeywell recorder in the control room.

21. Fuel inlet pressure (PSIG) - from a measurement taken near the L.P. fuel pump inlet. The accuracy of this measurement is ± 1 PSIG. It is read from a control room pressure gauge.

22. Oil tank temperature (°F) - from a closed tip iron-constantan thermocouple mounted in place of the oil tank drain plug which senses engine oil outlet temperature as measured at the oil tank. The accuracy of the measurement is ± 1°F. It is read on a control room temperature gauge.

23. Junction box temperature (°F) - from an iron-constantan thermocouple installed on the small mounting lug for the ballast resistor in the T5.1 thermocouple junction box. The accuracy of this measurement is ± 1°F. It is read from a control room temperature gauge.

24. Pilot fuel manifold pressure (PSIG) - from a pressure tap on the pilot manifold near the main manifold pressure tap. The accuracy of this reading is ± 25 PSIG. It is read from a control room pressure gauge.

25. Temperature limiter amplifier current (Milliamps) - measures current to the main fuel control limiting solenoid. Taken from pins 12 and 13 of amplifier test connector on the temperature limiter amplifier. The accuracy of this measurement is ± .5 milliamps. It was continuously recorded on an Offner Oscillograph recorder.

26. Ambient pressure (in HG) - read from barometer in control room.

27. Wet bulb temperature (°F) - measurement made periodically in the test cell using a sling psychrometer.

28. Dry bulb temperature (°F) - measurement made periodically in the test cell using a sling psychrometer.

VII DISCUSSION OF THE TEST

SUMMARY

An accelerated mission test of a TF41 (S/N 141677) with aircooled second stage high pressure turbine blades was conducted at the Air Force Aero Propulsion Laboratory's sea level engine test facility, "3" stand. A complete accelerated mission test normally consists of 263 endurance hours, made up of 305 "A" cycles, 60 "B" cycles, and 15 "C" cycles. Only 160 endurance hours (187 total operating hours) were completed in this test before the engine was returned to Allison to be refurbished for use in another test program. One hundred and eighty-seven (187) "A" cycles, 32 "B" cycles, and 9 "C" cycles were completed.

ENGINE RELATED INCIDENTS

In general, the TF41 engine tested in this program operated extremely well, with only a minimum number of mechanical problems. The more important engine related incidents that occurred during the test are summarized below:

- Low Idle Speed - the "as received" idle RPM (high pressure rotor speed) was approximately 150 RPM low. Adjustment was made according to T.O. procedure. Idle speed had to be adjusted up again after approximately 95 AMT hours.

- Fuel Leak After Shutdown - discovered after 35 AMT hours and traced to an improperly closing fuel shut-off valve. The problem was resolved by adjusting the valve actuation arm.

- High Oil Consumption - oil consumption increased gradually from negligible levels to almost 1.5 quarts per hour by the end of the test.

- Crack in L.P. Turbine Bearing Support Fairing - A 3 to 4 inch crack was discovered at approximately the 8 o'clock position on the fairing during the 50 hour phase inspection. The crack was repaired by stop drilling and welding.

- Clogged Fuel Filter - "pop out" button actuated after 130 AMT hours and again at 150 AMT hours. The problem was traced to a facility fuel filter deficiency and a new engine filter was installed each time.

- High Reading on Engine Failure Predictor (Ion Probe)- occurred at about 125 AMT hours indicating the potential for an imminent engine failure. (This device is undergoing development and was being run on the engine by the Air Force Institute of Technology at the request of the TF41 project office). The engine was shutdown and borescoped. No apparent damage was observed and testing was resumed. Turbine vibration levels appeared to be higher than before, but still below T.O. limits.

TEST PROCEDURES

Throughout this entire test program, the engine was operated in accordance with the procedures and limits contained in Air Force Tech Order, T.O. 2J-TF41-6 and Allison Publication Nr 1F2, TF41-A-1 Engine Operation and Service. Prior to each day's running, a pre-test checklist, including a visual inspection of the engine and test cell were completed. Oil level was checked several times during the day and rotor coast downs were recorded upon the last shutdown of each test period.

After initial installation in the test cell, a short series of steady-state and transient runs were made in order to check out the engine, facility and instrumentation. A walk around inspection of the engine was carried out at idle power to check for leaks. Having been satisfied that the engine, facility and instrumentation were all functioning properly, actual testing was initiated

according to the procedures contained in the test plan (see appendix D).

A functional check of the engine's limiters, governors, and schedules was performed before the endurance portion of the test and a similar check was planned after every 50 AMT hours of testing. A pre-test steady-state power calibration, between approximately 50% power and maximum power was also carried out. An additional series of steady-state points were run to define the high pressure compressor rotor speed/power lever angle relationship needed to input the test cycles into the automatic throttle controller. Additional calibrations were scheduled in 100 AMT hour intervals and after completion of the test.

Engine maintenance and inspections were planned at 50 hour intervals according to Allison publication 1F2. Borescoping of the engine was to be performed after every 100 AMT hours. Oil samples were taken after approximately 25 hours of engine operating time.

During the test operation, all facility and engine instrumentation was monitored by the test operator and the test cell observer. Data was only recorded during the six minute constant power level operation at intermediate power (referred to as the "Intermediate Power Flat") which occurs near the end of every "A" cycle and was processed by a data reduction computer program (using methods outlined in appendix A) after each day's run. However, thrust, fuel flow, low pressure and high pressure rotor speeds, exhaust gas temperature, ambient temperature, and temperature limiter amplifier current were recorded continuously on an oscillograph recorder.

The actual endurance portion of this accelerated mission test was run in a series of "blocks". Each block consisted of the following sequence of cycles; 20 "A" cycles followed by 4 "B" cycles, followed by 1 "C" cycle.

INLET TEMPERATURE/TURBINE STATOR INLET TEMPERATURE (T4) TIME SUMMARY

Previous TF41 AMT tests were run with controlled engine inlet temperature. Forty-one per cent of the test was run at 70°F ± 5°F, 38% was run at 90°F, ± 5°F, 9% was run at 110°F ± 5°F and the

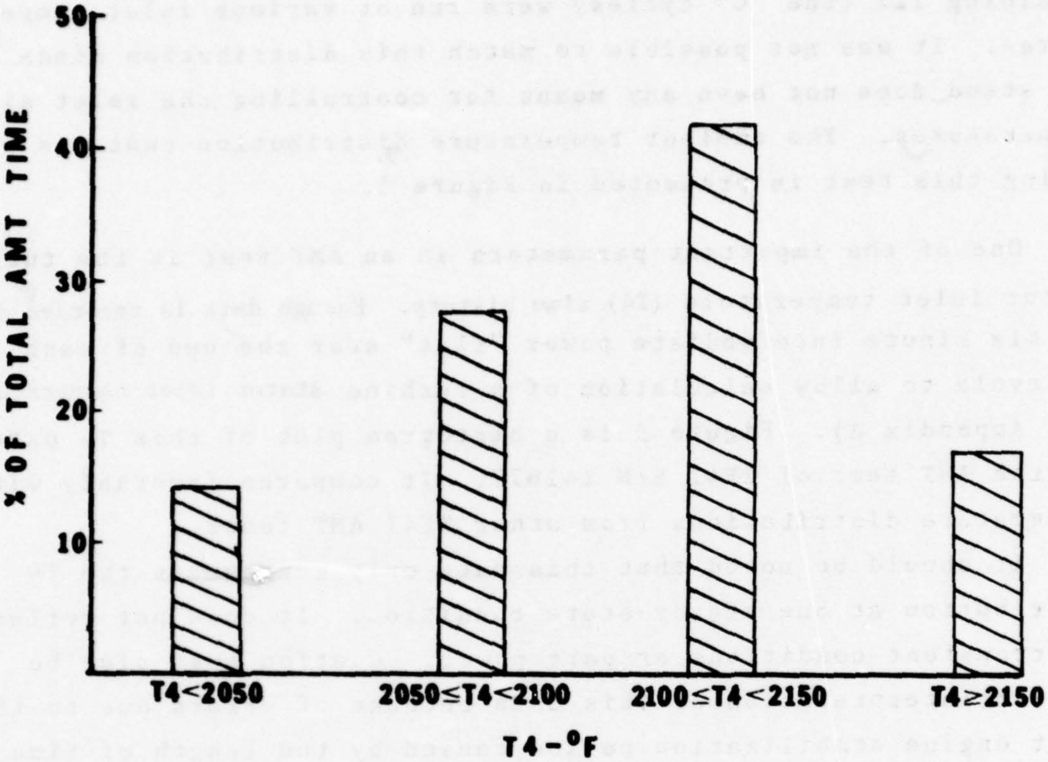
remaining 12% (the "C" cycles) were run at various inlet temperatures. It was not possible to match this distribution since "3" stand does not have any means for controlling the inlet air temperatures. The ambient temperature distribution that was run during this test is presented in Figure 5.

One of the important parameters in an AMT test is the turbine stator inlet temperature (T4) time history. Enough data is recorded during the six minute intermediate power "flat" near the end of each "A" cycle to allow calculation of a turbine stator inlet temperature (see Appendix A). Figure 5 is a histogram plot of this T4 data for the AMT test of TF41 S/N 141677. It compares favorably with temperature distributions from other TF41 AMT tests.

It should be noted that this data only represents the T4 distribution at one steady-state condition. It does not reflect any transient conditions or part power. Caution must also be used in interpretation of this data because of errors due to the short engine stabilization period caused by the length of time required to manually record the raw data.

FUNCTIONAL CHECK DATA

Functional checks of the engine's limiters, governors, and schedules were performed before the test and at 50 AMT hours, and 100 AMT hours. The scheduled check at 150 AMT hours was eliminated due to the proximity of the test termination date. The following checks were made according to T.O. 2J-TF41-6 procedures: IGV ram closing schedule (check not made at 50 AMT hours) NL governor, P3 limiter, T5.1 pulldown, and acceleration control unit (ACU) and deceleration control unit (DCU). Mass flow limiter and NH governor were not checked due to a lack of the proper equipment. The results of these checks are contained in Tables 1 through 4 and on figure 6. Note that several of the parameters were slightly out of limits but adjustments were not made due to a lack of the proper adjustment tools. Discussions with Allison engineers confirmed that these apparent out of limit conditions, even if real, were not important to the overall objectives of this test.



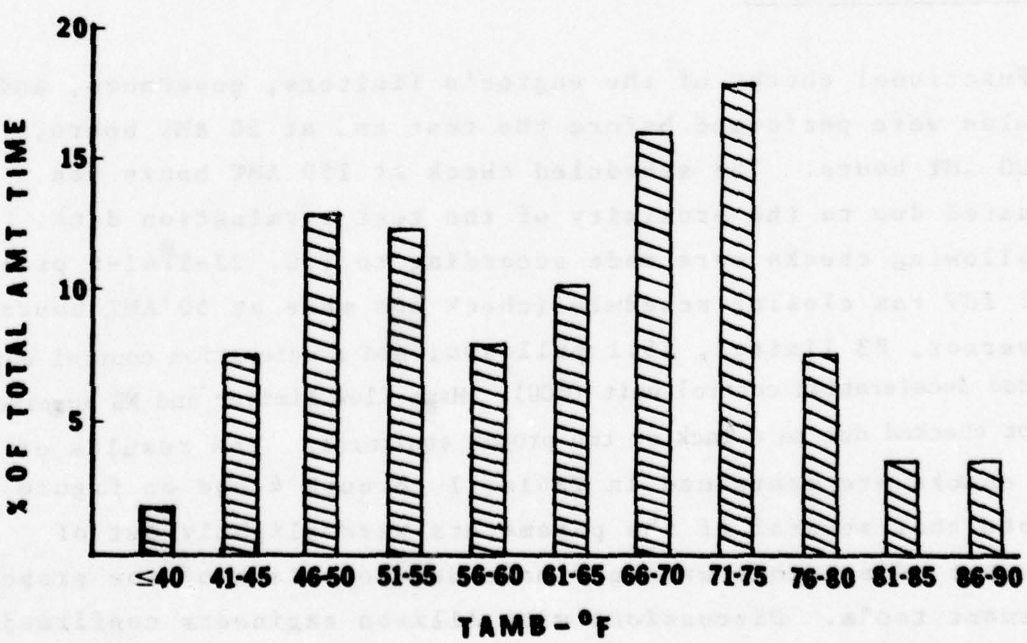


FIGURE 5 - AMBIENT TEMPERATURE AND CALCULATED TURBINE STATOR INLET TEMPERATURE TIME HISTORY

TABLE 1 NL GOVERNOR CHECK

	T.O. LIMIT	0 HOURS	50 HOURS	100 HOURS
NL (RPM)	7948 ⟶ 8002	7990	8020*	7980

* High but no adjustment made

TABLE 2 P3 LIMITER CHECK

	T.O. LIMIT	0 HOURS	50 HOURS	100 HOURS
P3 (PSIG)	145 --- 155	148	145	145

TABLE 3 T5.1 PULLDOWN CHECK

	T.O. LIMIT	0 HOURS	50 HOURS	100 HOURS
T5.1 (^oF)	884.5 --- 888.5	887	875*	885

*Low but no adjustment made

TABLE 4 Acceleration and Deceleration Time Checks

	T.O. LIMIT			0 HOURS	50 HOURS	100 HOURS
TAMB (^oF)	75	72	48	75^o	72^o	48^o
ACU^x (Sec)	5.5-7.5	5.5-7.5	5.5-7.5	5.5	4.75*	4.9
DCU^x (Sec)	4.7-6.7	4.6-6.6	4.4-6.4	5.88	5.0	5.3

^{x} Average of 3 readings

* Low but no adjustment made

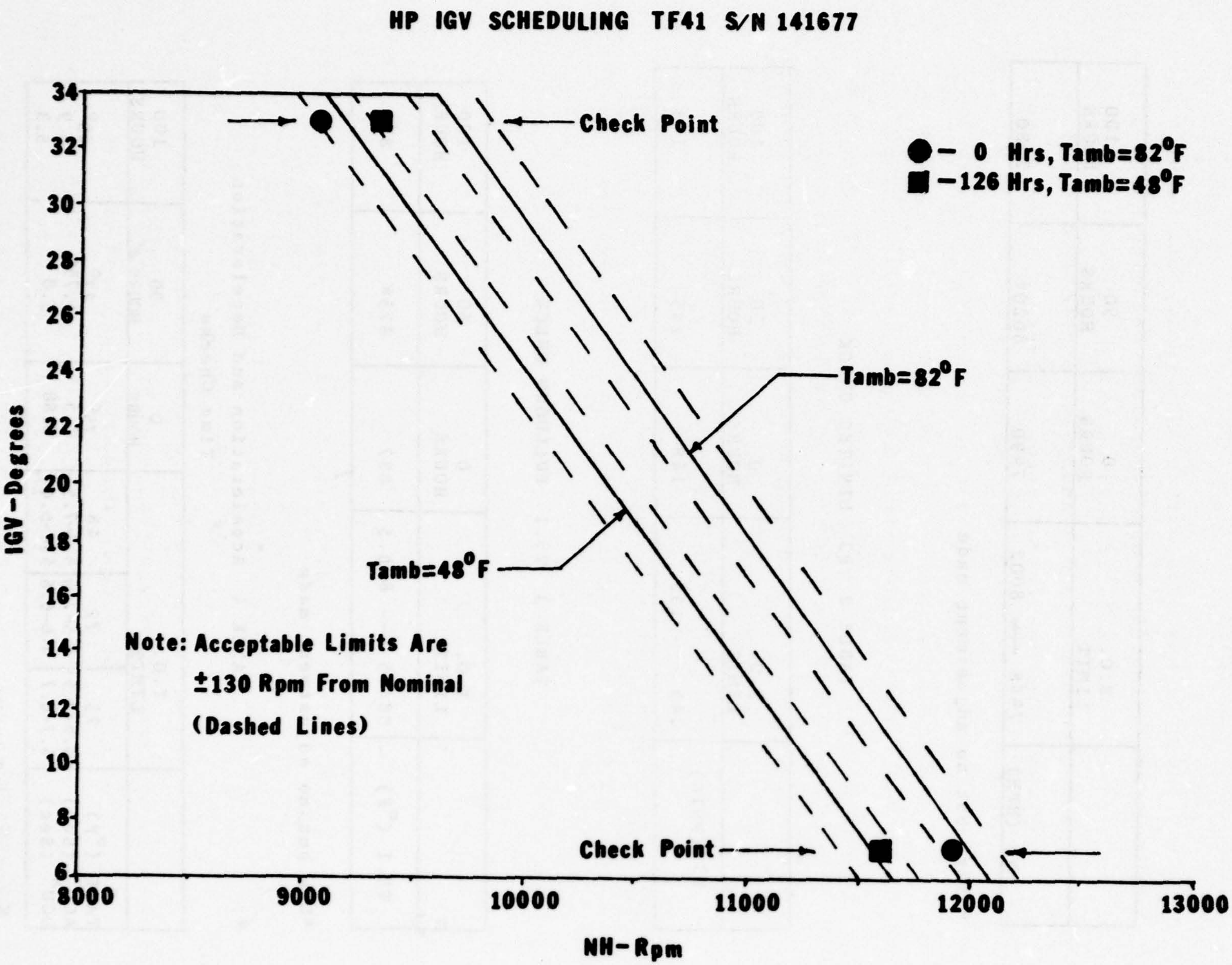


FIGURE 6 - H.P. IGV SCHEDULING

OIL SAMPLING/CONSUMPTION

MIL-L-7808 oil was used during this test. Oil samples were taken after approximately every 25 engine operating hours and sent to the Air Force Aero Propulsion Laboratory's Fuels and Lubes Division for Spectrometric Oil Analysis Program (SOAP) and ferrograph analyses. The results of these analyses are contained in Appendix B.

All oil added during the test was recorded. Figures 7 and 8 are plots of oil consumption between fills and overall oil consumption as a function of total engine operating time. Note that overall oil consumption was increasing throughout most of the duration of the test and was well above the T.O. limit for a TF41 of .5 qts/hr. Allison felt that this high oil consumption would not have a significant impact on the primary objective of this test and therefore it was continued despite the out of limit condition.

PHASE INSPECTIONS/BORESCOPE

Engine inspections were performed at 50 and 100 AMT hours according to the instructions in Allison publication Nr 1F2, Section 7. The 150 hour inspection was waived due to the proximity of the test termination date. Two anomalies were discovered during these inspections. At 50 hours a 3 to 4 inch crack was discovered in the low pressure turbine bearing support fairing. The crack was stop drilled and welded. At 100 AMT hours, a rather large metal particle was found on the gear box chip detector. It was analyzed by the Fuels and Lubes Division of the Air Force Aero Propulsion Laboratory. The results of the analysis did not indicate a serious problem and the report is contained in Appendix B.

At approximately 100 AMT hours the engine was borescoped. It was prepared for borescoping by AFAPL personnel. All fuel nozzles, HPT-2 borescope port plug and intermediate case plugs were removed. The borescope inspection was performed by the Allison field service group. No problems were found. The details are presented in Appendix B.

After approximately 125 AMT hours an "Engine Imminent Failure Warning" device which was being tested on a non-interference basis by ASD/YZS41 gave an indication of a potential engine failure. ASD/YZS41 requested a borescope inspection. The engine was prepared

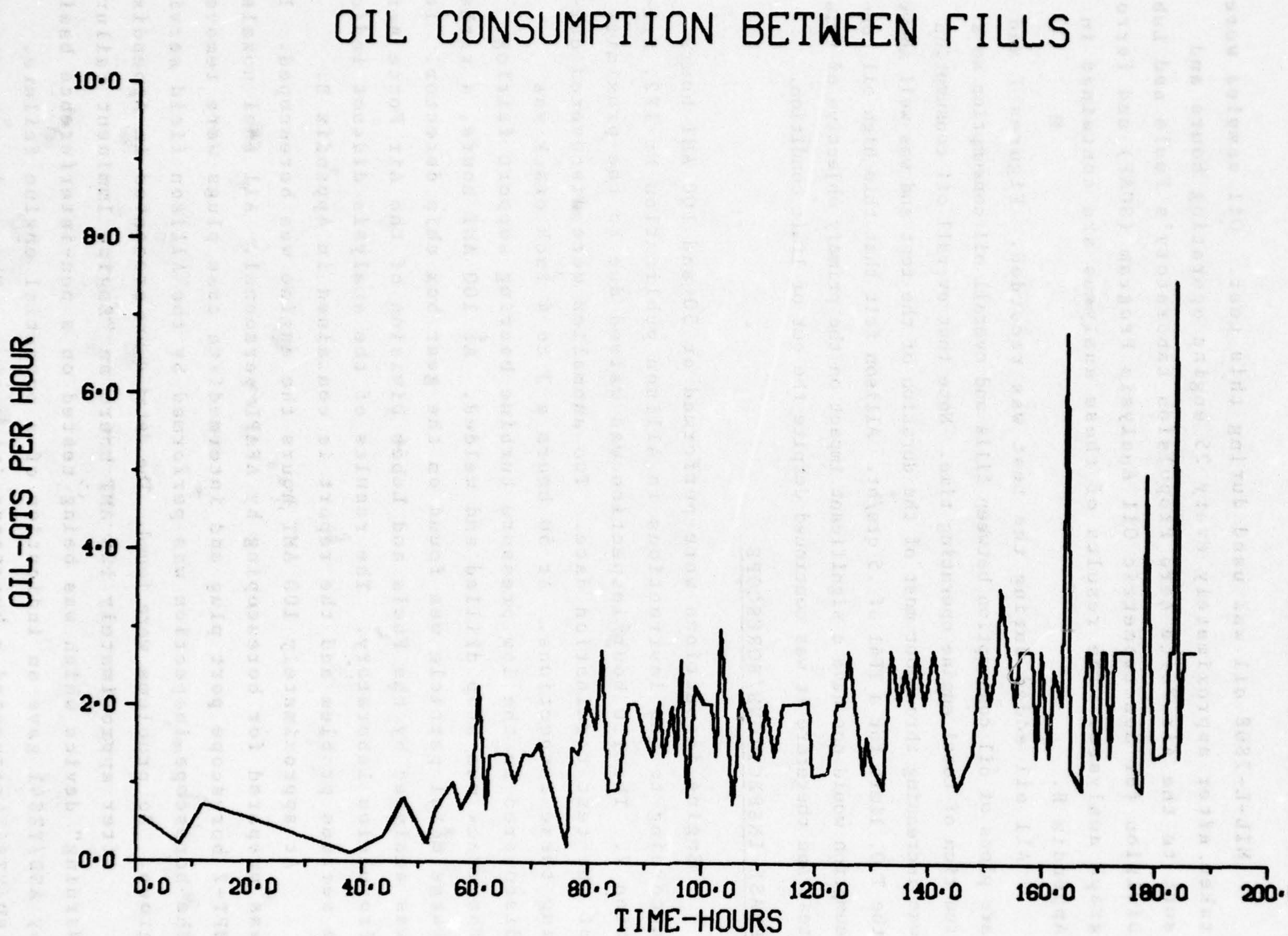


FIGURE 7 - OIL CONSUMPTION BETWEEN FILLS

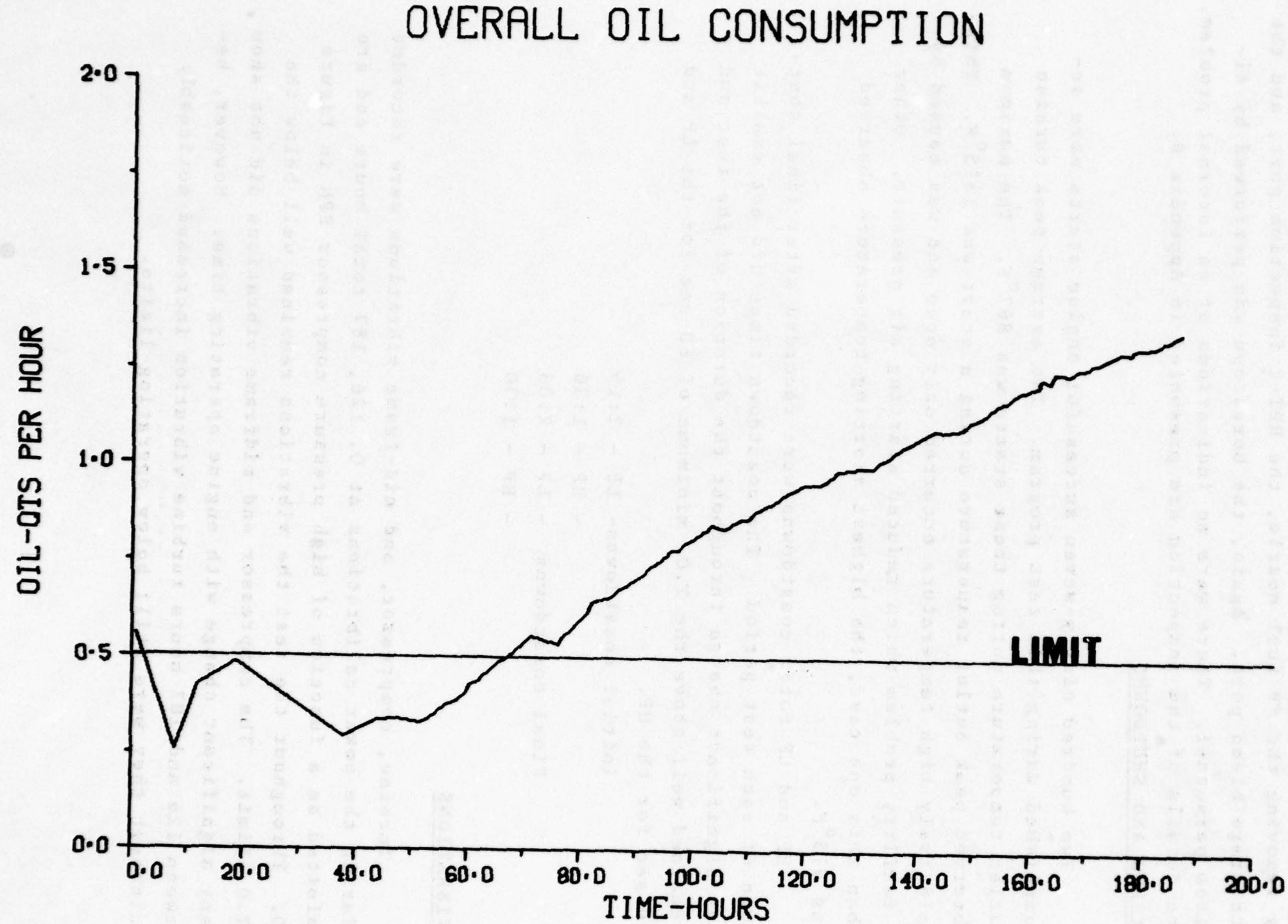


FIGURE 8 - OVERALL OIL CONSUMPTION

by removing the #9 fuel nozzle, the HPT-2 inspection port, and the 7th stage bleed port. Again, the borescope was performed by Allison personnel. There were no indications of an internal problem. The details of the inspection are presented in Appendix B.

STARTS AND SHUTDOWNS

Two hundred ninety-seven successful engine starts were accomplished during this test program. The average peak turbine outlet temperature during these starts was 867°F. The maximum observed peak outlet temperature during a start was 1115°F. This relatively high temperature occurred only once and was caused by a facility problem which reduced starting air pressure. Other than this one case, the highest starting temperature observed was 975°F.

HP and LP rotor coastdowns were recorded after final shutdown of each test period. The coastdown times did not exhibit any significant change throughout the duration of the test and remained well above the T.O. minimums of 60 sec for the LP and 20 sec for the HP.

Initial coastdowns	LP	-	2:15
	HP	-	1:30
Final coastdowns	LP	-	2:03
	HP	-	1:30

VIBRATIONS

Turbine, compressor, and mid-frame vibrations were recorded during the power calibrations at 0, 126, 187 total hours and are plotted as a function of high pressure compressor RPM in Figure 9. Throughout the test the vibrations remained well below the T.O. limit. The compressor and midframe vibrations did not show any significant change with engine operating time. However, between 126 and 187 hours turbine vibration increased noticeably although they were still below operating limits.

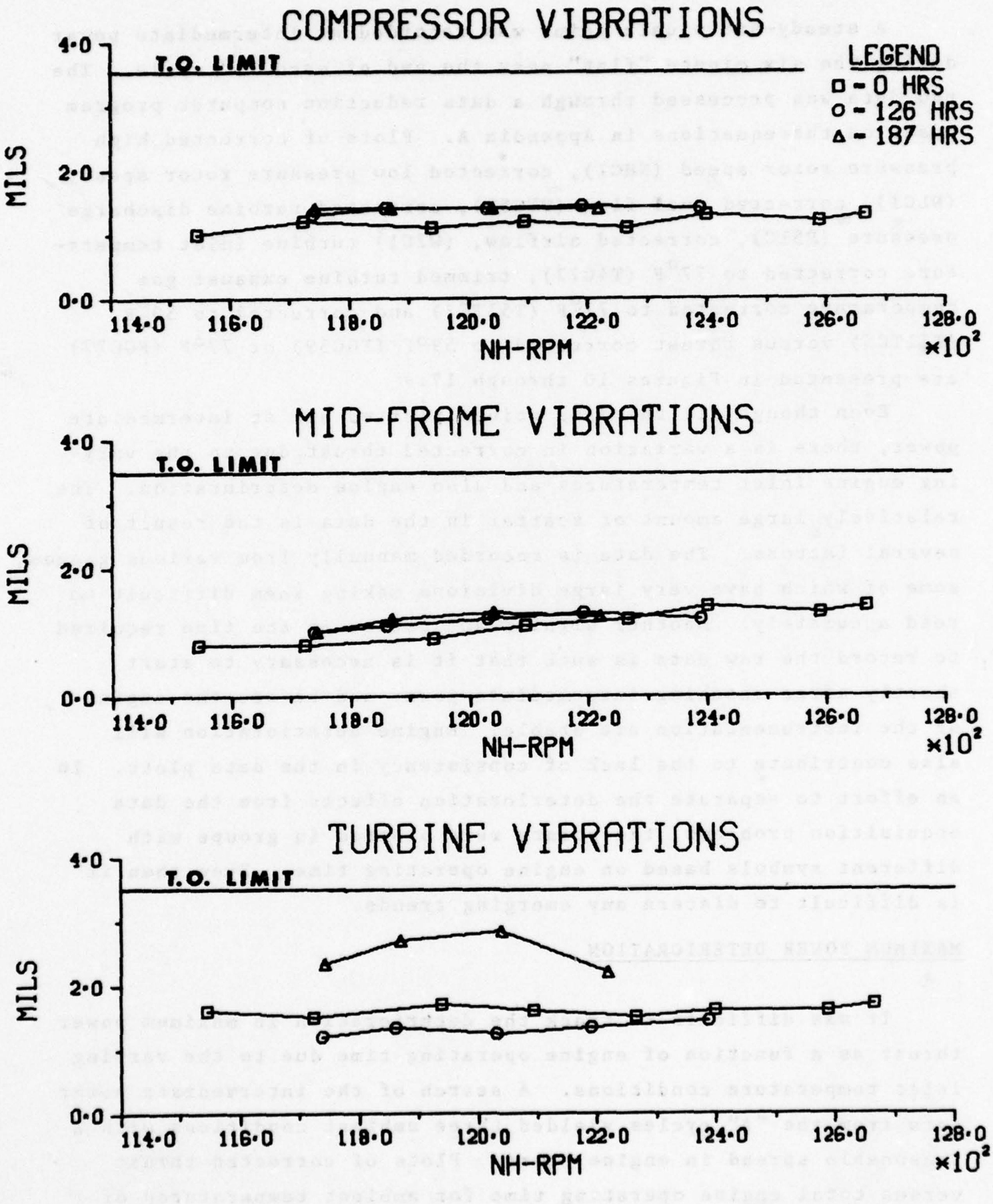


FIGURE 9 - ENGINE VIBRATION HISTORY

"A" CYCLE PERFORMANCE DATA

A steady-state data point was recorded at intermediate power during the six minute "flat" near the end of each "A" cycle. The raw data was processed through a data reduction computer program based on the equations in Appendix A. Plots of corrected high pressure rotor speed (NHC1), corrected low pressure rotor speed (NLC1), corrected fuel flow (WFC59), corrected turbine discharge pressure (P51C), corrected airflow, (W2C1) turbine inlet temperature corrected to 77^{o}F (T4C77), trimmed turbine exhaust gas temperature corrected to 77^{o}F (T51TC7) and corrected to 59^{o}F (T51TC5) versus thrust corrected to 59^{o}F (FGC59) or 77^{o}F (FGC77) are presented in Figures 10 through 17.

Even though all the data points plotted are at intermediate power, there is a variation in corrected thrust due to the varying engine inlet temperatures and also engine deterioration. The relatively large amount of scatter in the data is the result of several factors. The data is recorded manually from various gauges, some of which have very large divisions making them difficult to read accurately. Another significant factor is the time required to record the raw data is such that it is necessary to start shortly after reaching intermediate power and before the engine or the instrumentation are stable. Engine deterioration will also contribute to the lack of consistency in the data plots. In an effort to separate the deterioration effects from the data acquisition problems, the points were plotted in groups with different symbols based on engine operating time. Even then it is difficult to discern any emerging trends.

MAXIMUM POWER DETERIORATION

It was difficult to track the deterioration in maximum power thrust as a function of engine operating time due to the varying inlet temperature conditions. A search of the intermediate power data from the "A" cycles yielded three ambient conditions with a reasonable spread in engine hours. Plots of corrected thrust versus total engine operating time for ambient temperatures of

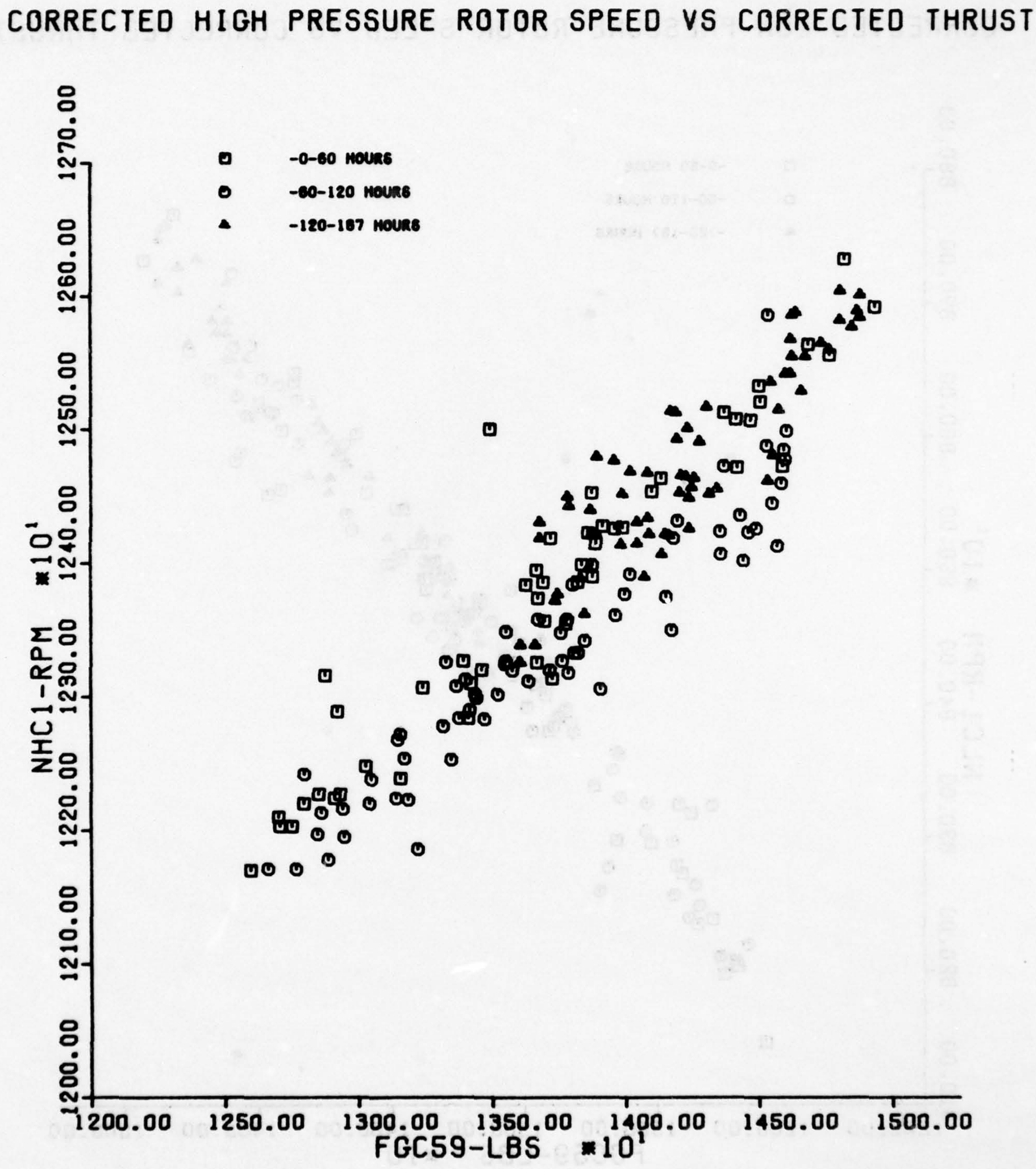


FIGURE 10 - CORRECTED HIGH PRESSURE ROTOR SPEED VERSUS CORRECTED THRUST

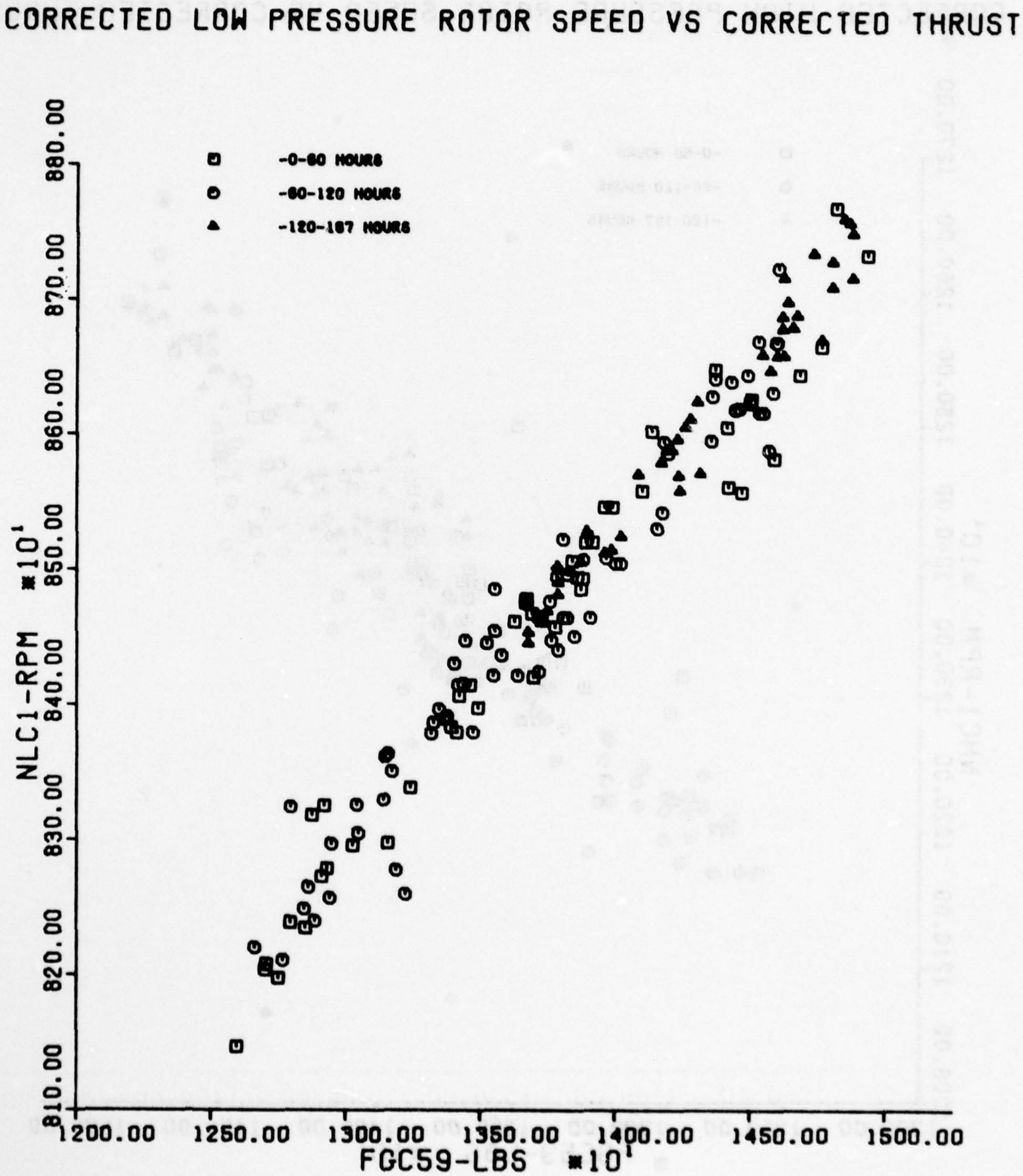


FIGURE 11 - CORRECTED LOW PRESSURE ROTOR SPEED VERSUS CORRECTED THRUST

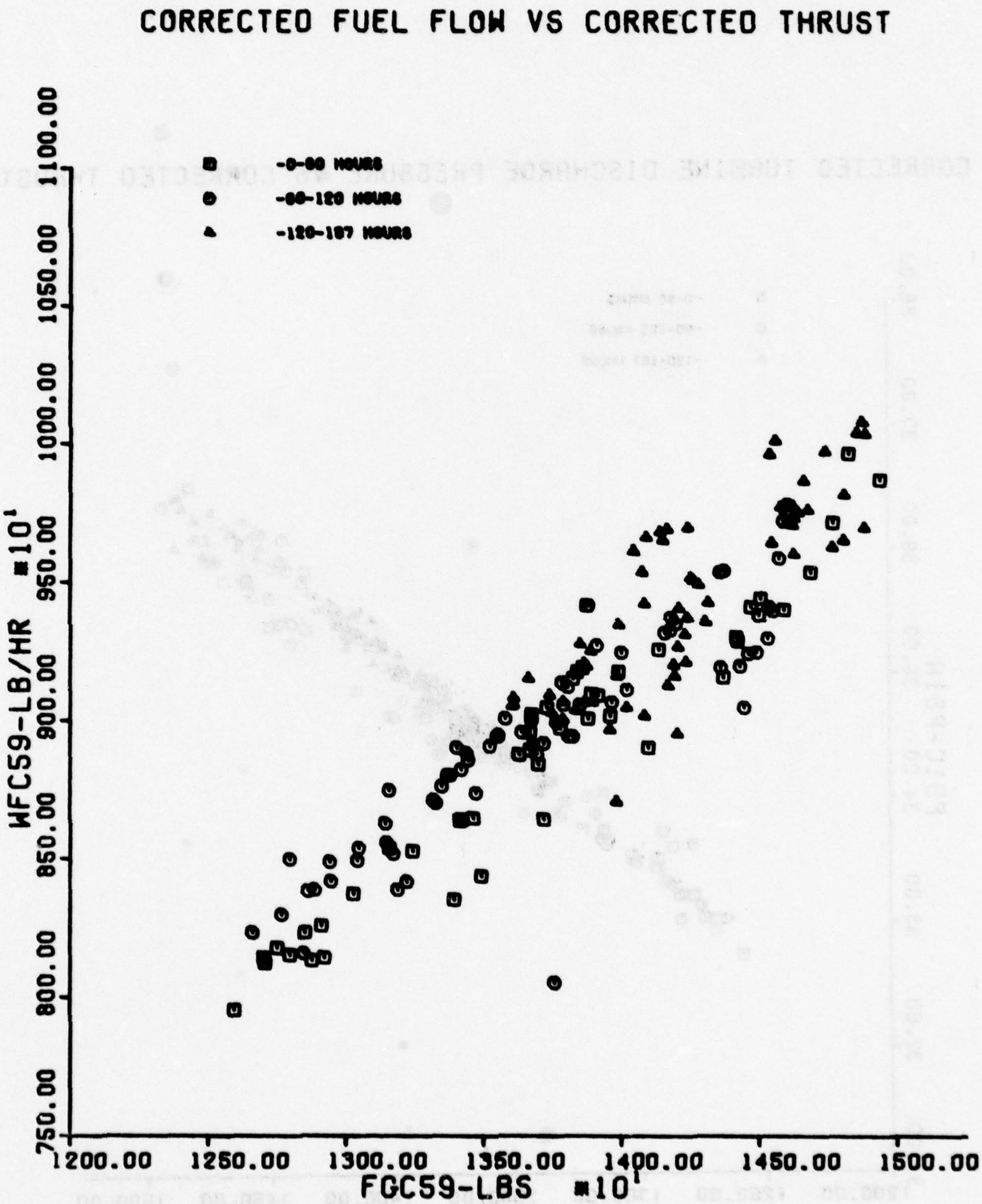


FIGURE 12 - CORRECTED FUEL FLOW VERSUS CORRECTED THRUST

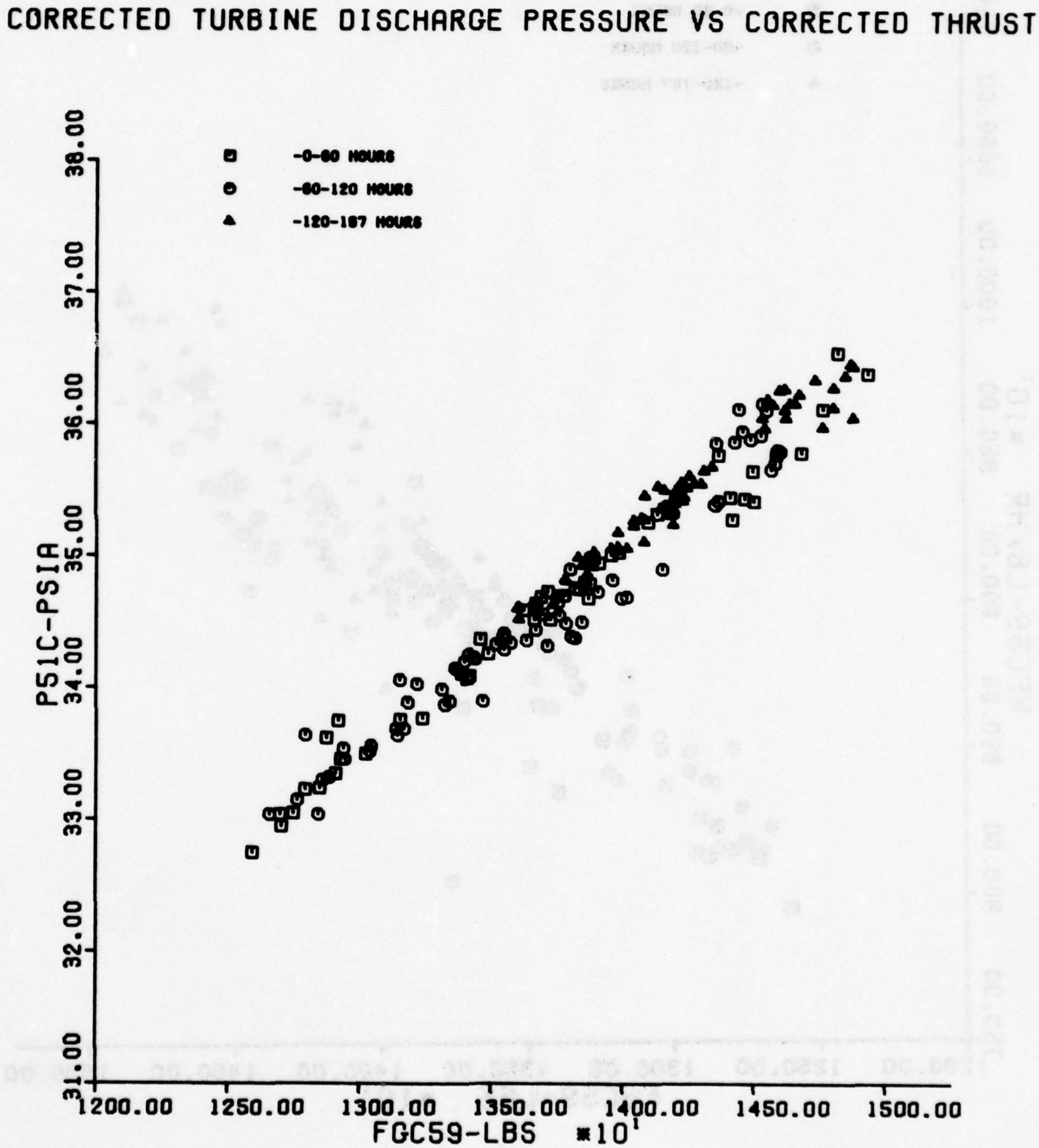


FIGURE 13 - CORRECTED TURBINE DISCHARGE PRESSURE VERSUS CORRECTED THRUST

CORRECTED INLET AIRFLOW VS CORRECTED THRUST

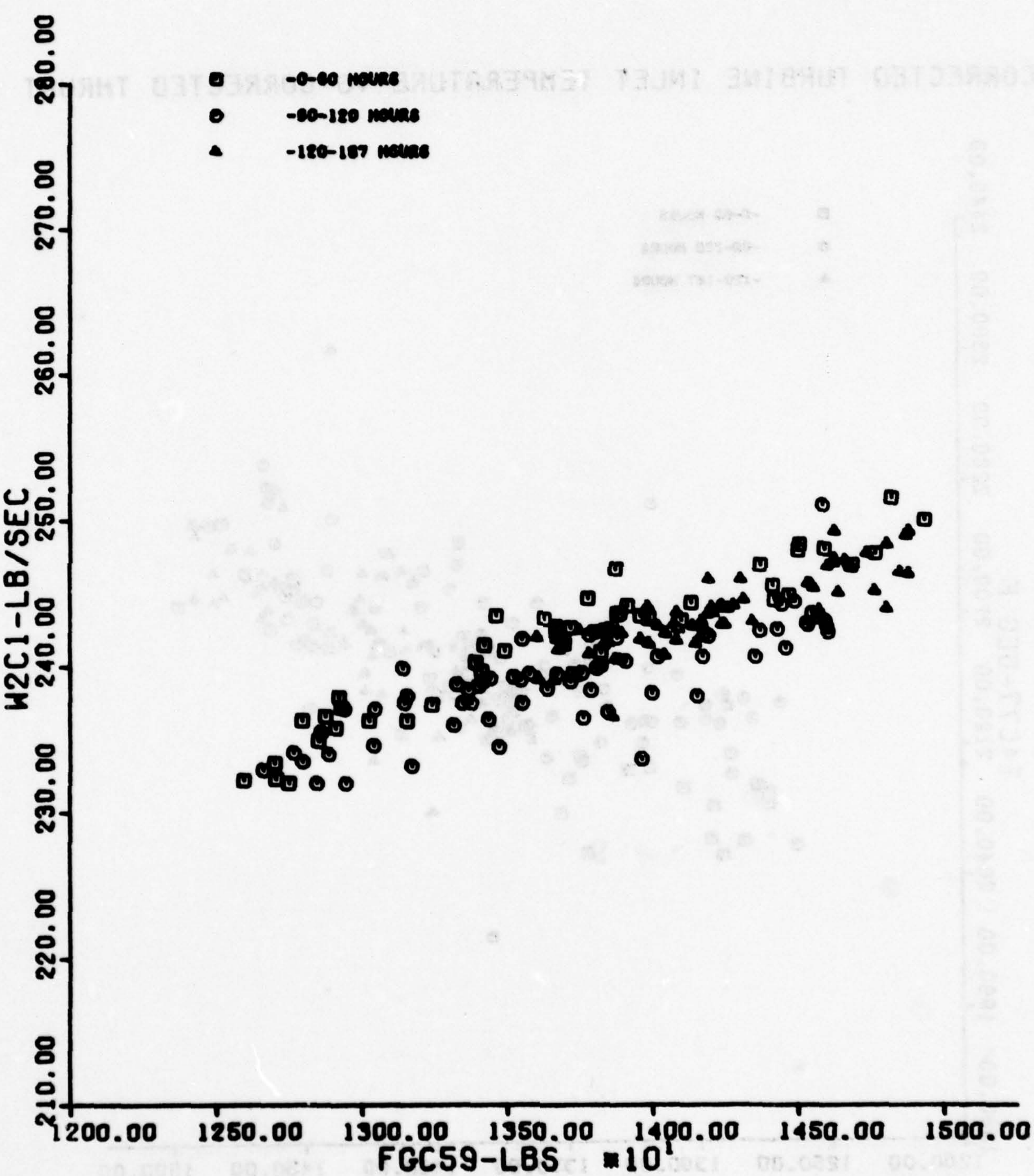


FIGURE 14 - CORRECTED INLET AIRFLOW VERSUS CORRECTED THRUST

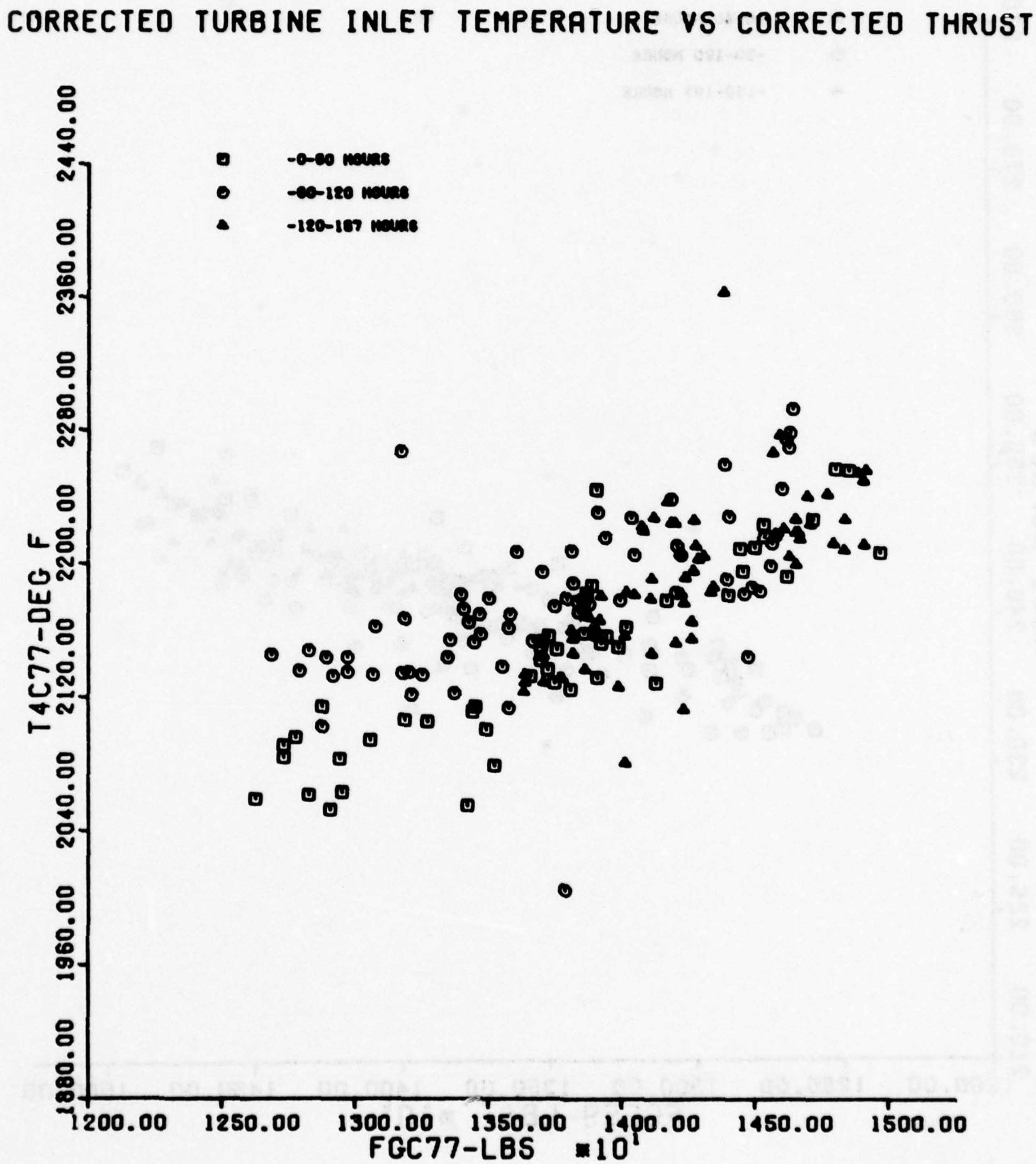


FIGURE 15 - CORRECTED TURBINE STATOR INLET TEMPERATURE VERSUS CORRECTED THRUST

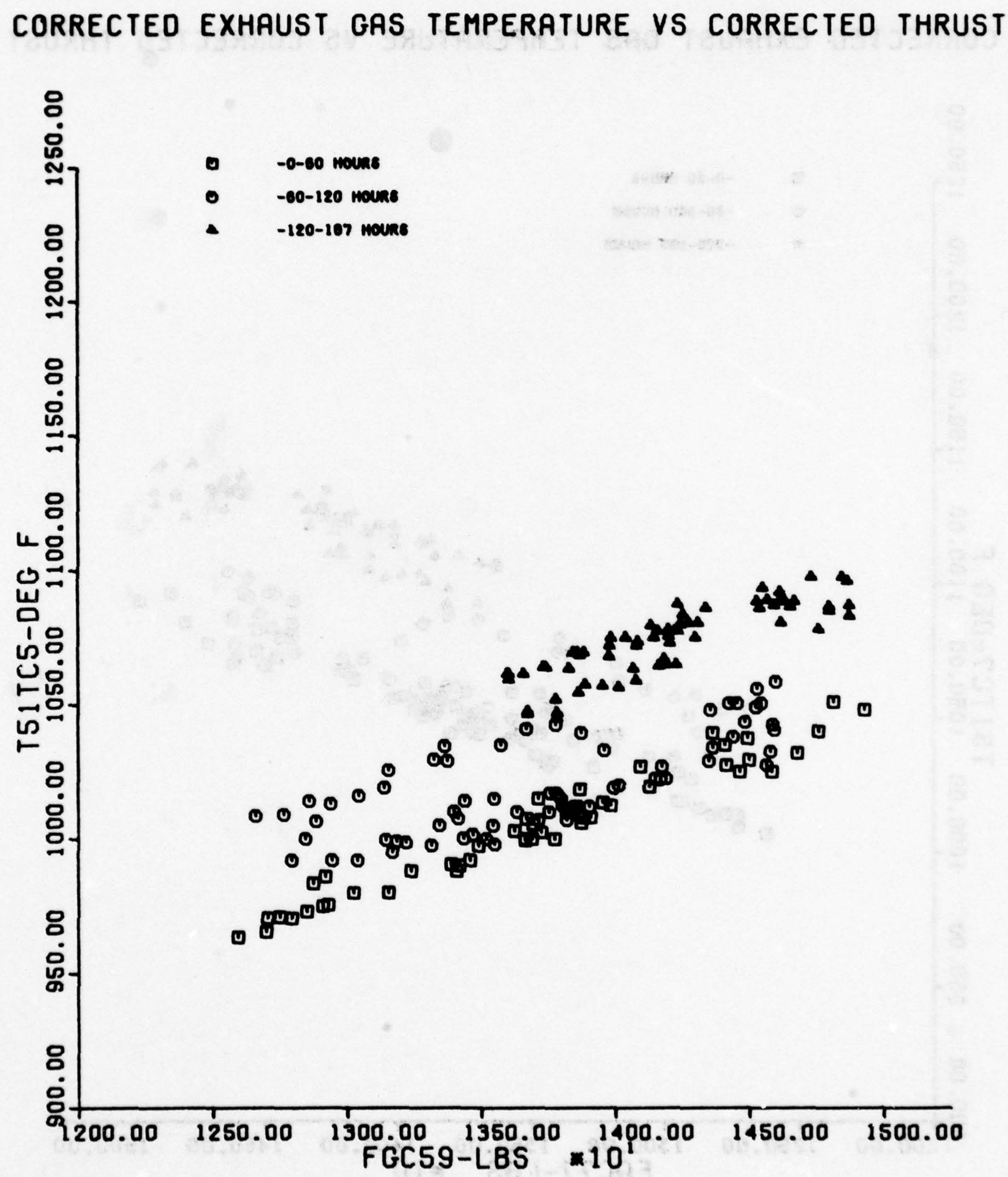


FIGURE 16 - CORRECTED EXHAUST GAS TEMPERATURE VERSUS CORRECTED THRUST

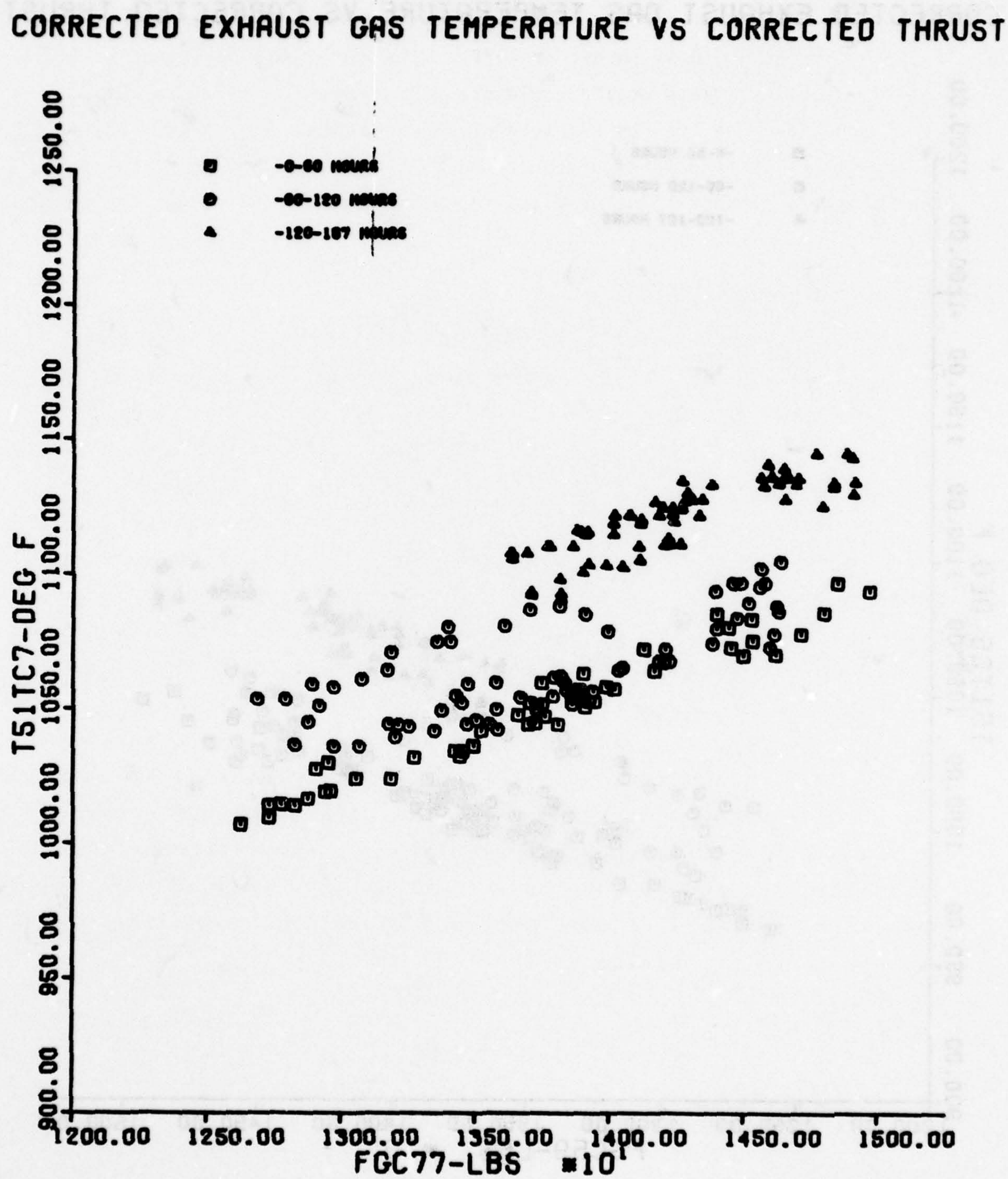


FIGURE 17 - CORRECTED EXHAUST GAS TEMPERATURE VERSUS CORRECTED THRUST

60°F, 67°F, and 73°F are presented in Figures 18 through 20. The data points on these plots also represent operation at a constant exhaust gas temperature limit of 1067°F. The data shows that, over the first 125 engine operating hours (approximately 100 AMT hours) the engine lost approximately 7.5% thrust at 60°F, 8.2% thrust at 67°F, and 8.5% thrust at 73°F. This represents operation at a constant trim setting. This engine could not be retrimmed to gain some of the lost performance because its "as received" trim was already at the turbine inlet temperature limit. Extrapolating these trends out to 187 engine operating hours indicates there is potential for over 10% in thrust loss by the end of the test.

PERFORMANCE CALIBRATIONS

Steady-state power calibrations were performed before the AMT test, after 100 AMT hours (126 total test hours) and after the AMT test (187 total test hours). The engine was allowed to stabilize for 5 minutes before the data was recorded at four or five power settings between 8500 pounds thrust and intermediate power. The data was then corrected according to the procedures outlined in Appendix A. Note that the three calibrations were performed at different inlet temperatures which impacts intermediate power thrust levels. The pre-endurance calibration was run at 79°F inlet temperature, the 100 hour calibration was run at 50°F, and the post-test calibration was performed at 56°F. Plots of this corrected data for the three calibrations are presented in Figures 21 through 30. In an effort to aid in the interpretation of this data, the percent change in each corrected parameter that occurred between each calibration run was calculated at two different thrust levels (13,500 lbs and 11,000 lbs). This data is presented in Table 5. A detailed analysis of this part power performance calibration is also presented in Section VIII.

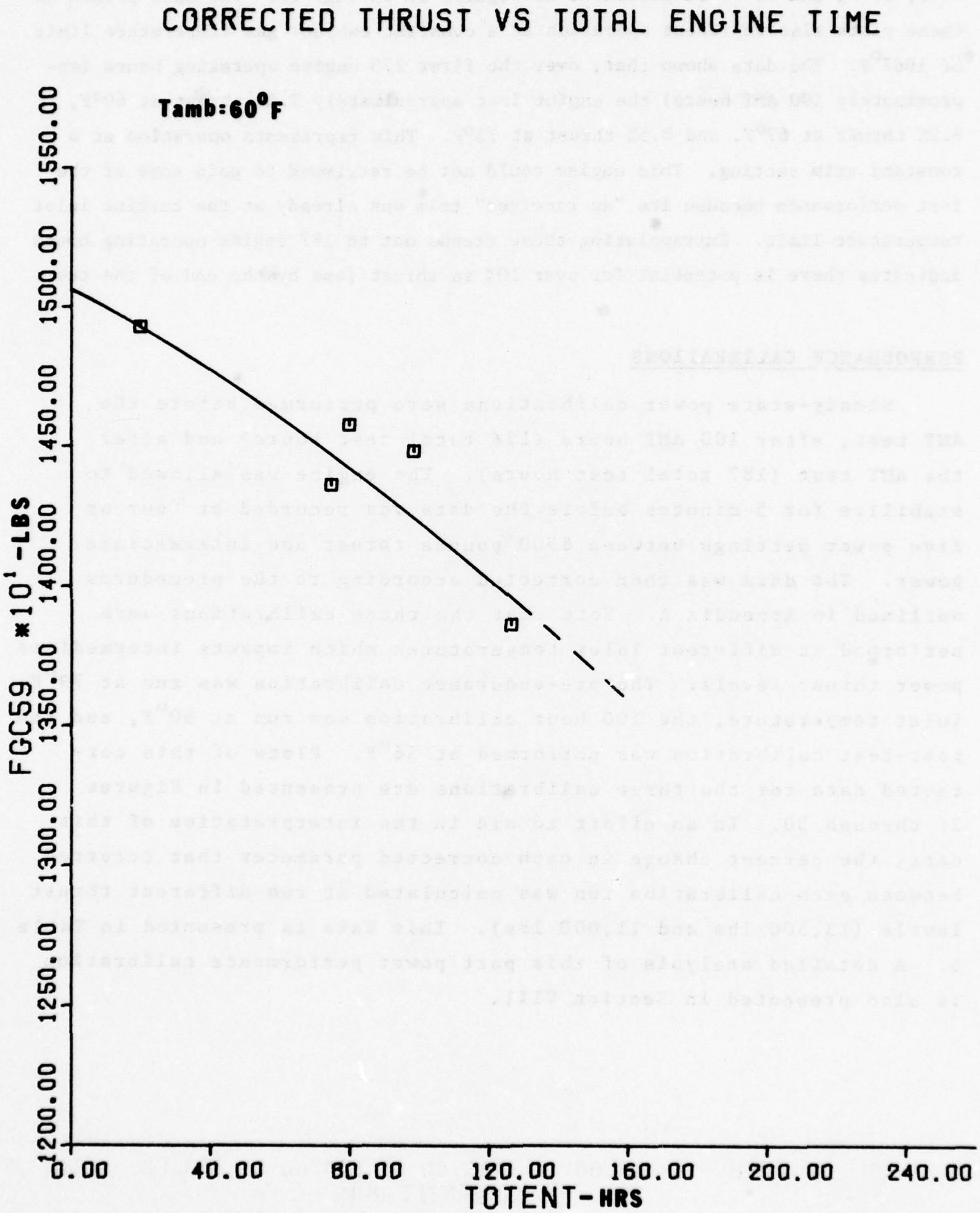


FIGURE 18 - CORRECTED THRUST VERSUS TOTAL ENGINE TIME TAMB = 60°F

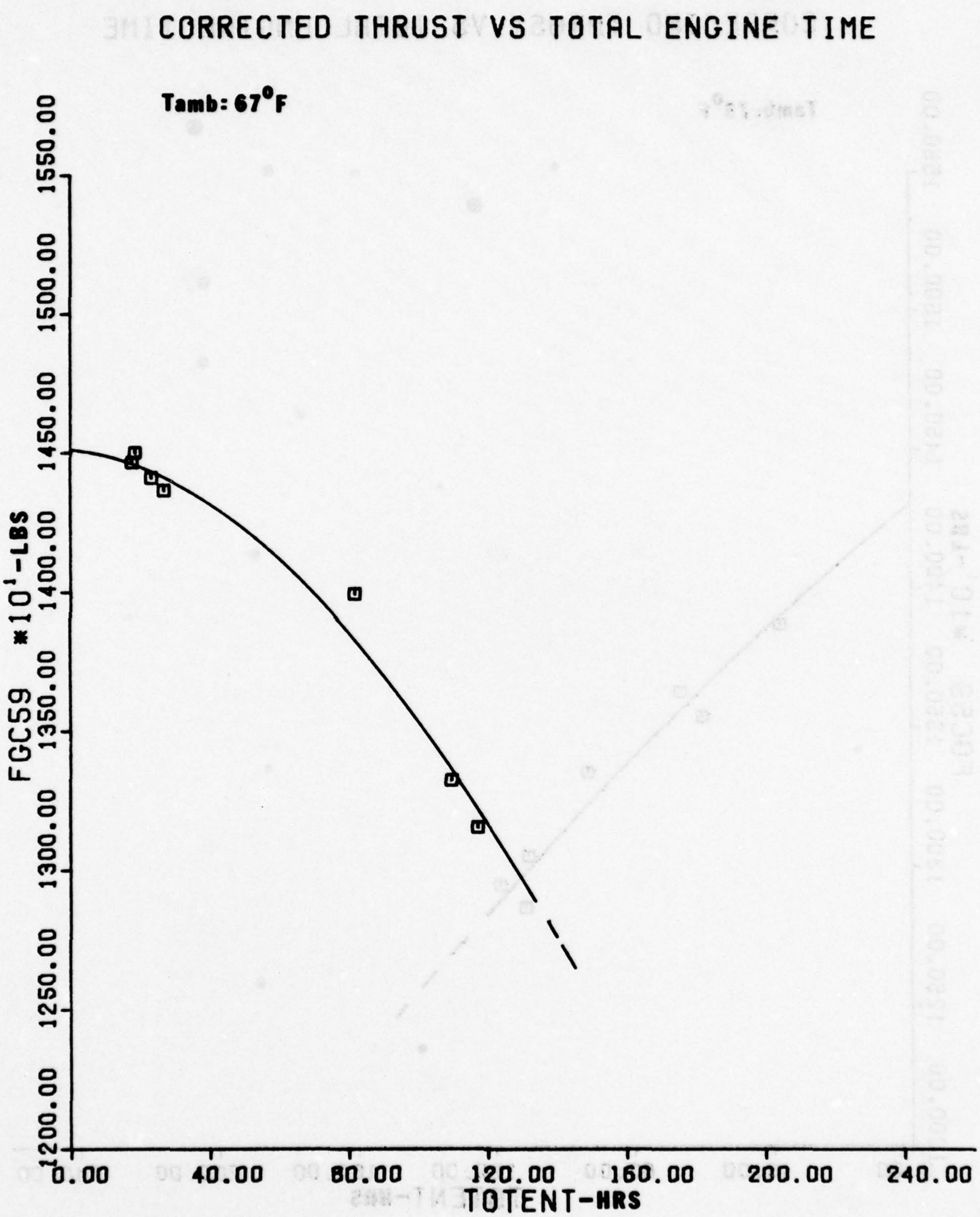


FIGURE 19 - CORRECTED THRUST VERSUS TOTAL ENGINE TIME TAMB = 67°F

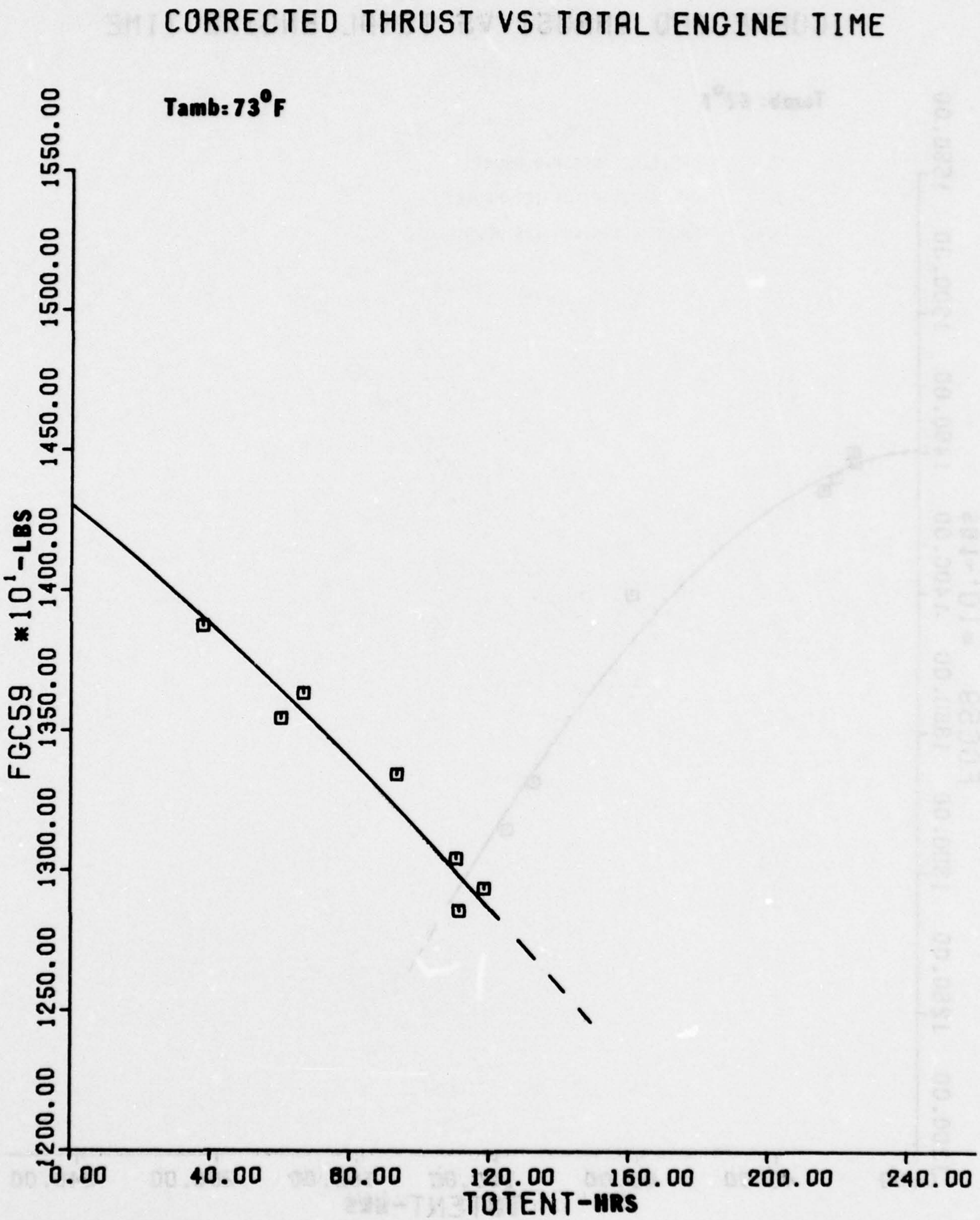


FIGURE 20 - CORRECTED THRUST VERSUS TOTAL ENGINE TIME TAMB = 73°F

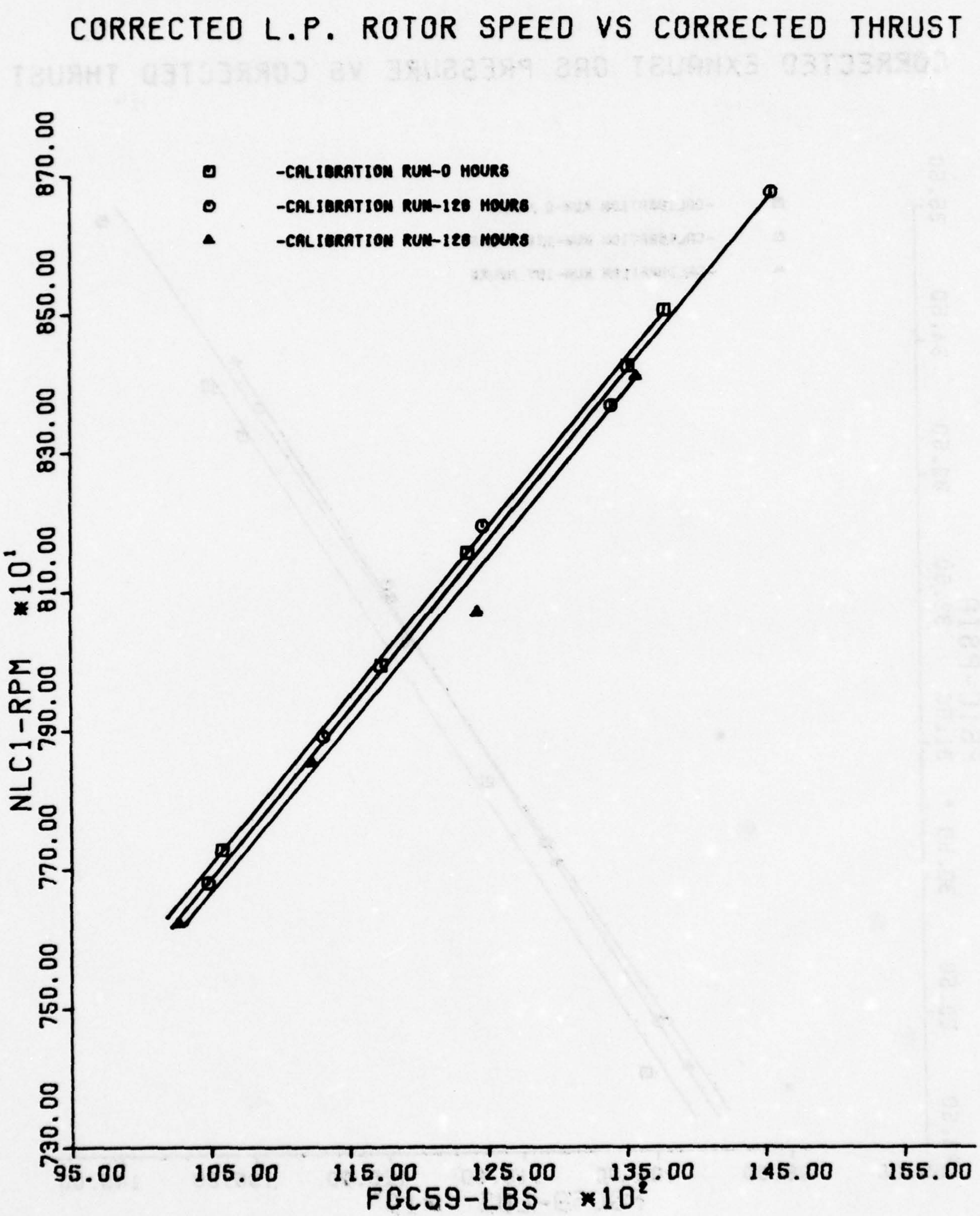


FIGURE 21 - CORRECTED L.P. ROTOR SPEED VERSUS CORRECTED THRUST

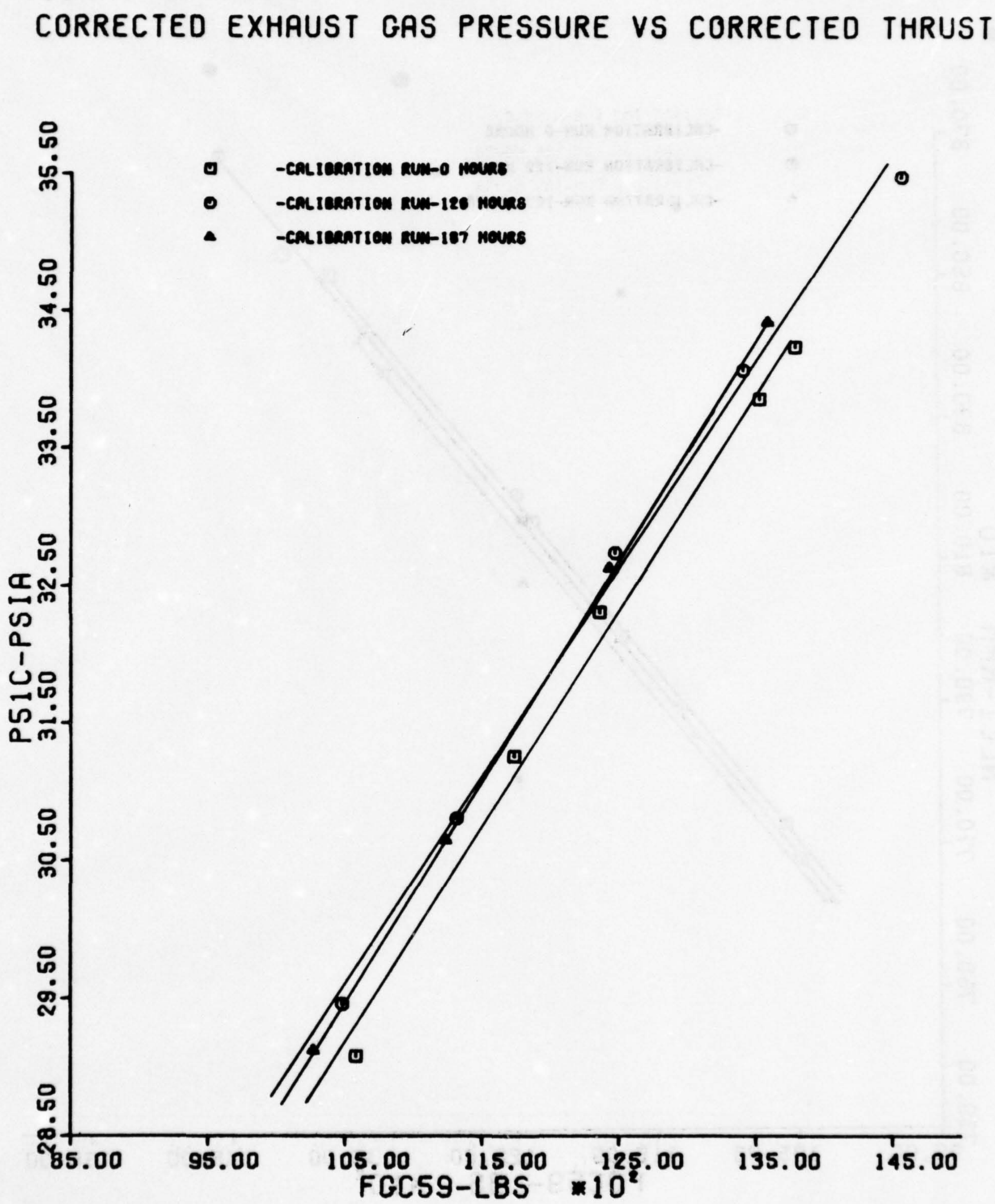


FIGURE 22 - CORRECTED EXHAUST GAS PRESSURE VERSUS CORRECTED THRUST

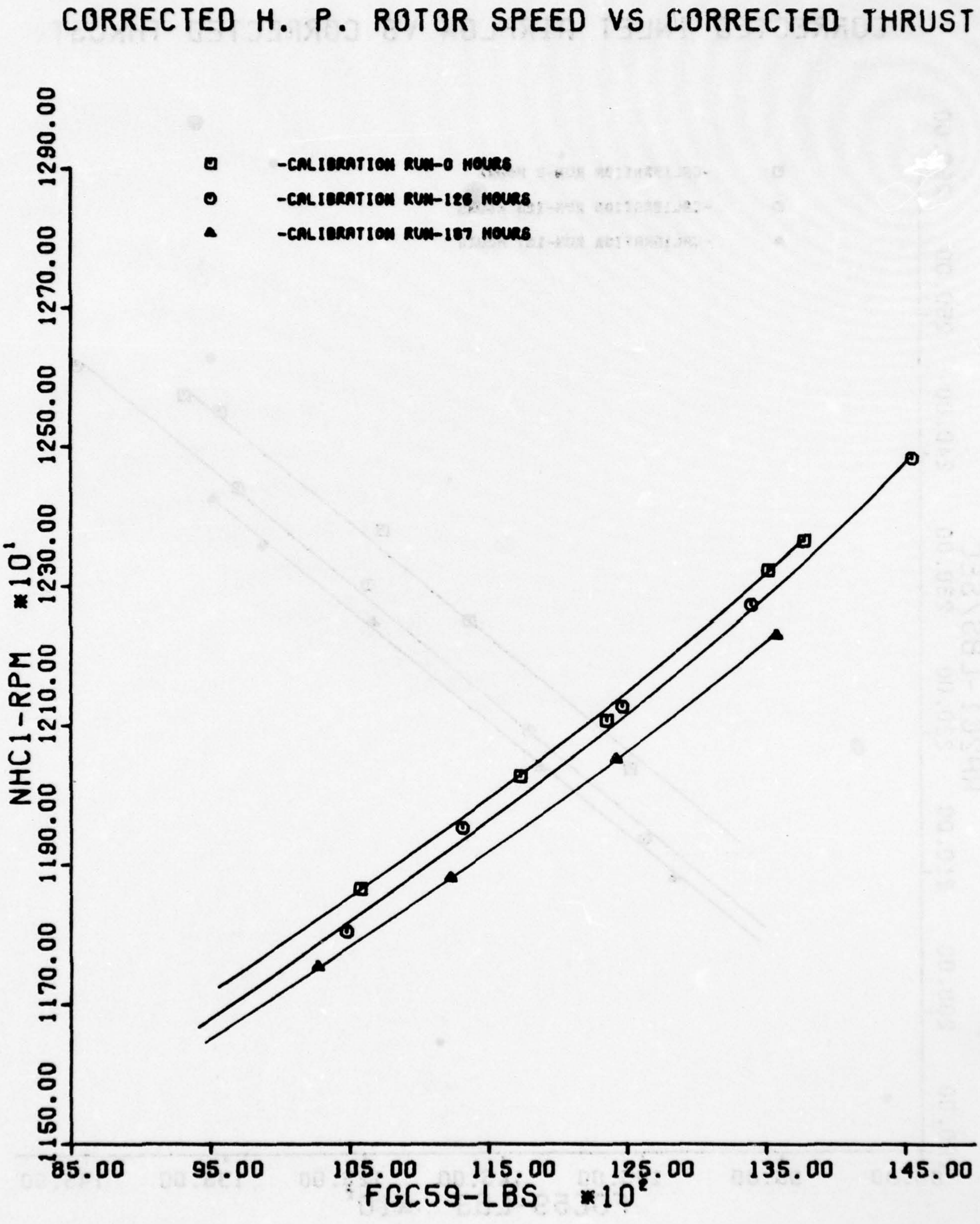


FIGURE 23 - CORRECTED H.P. ROTOR SPEED VERSUS CORRECTED THRUST

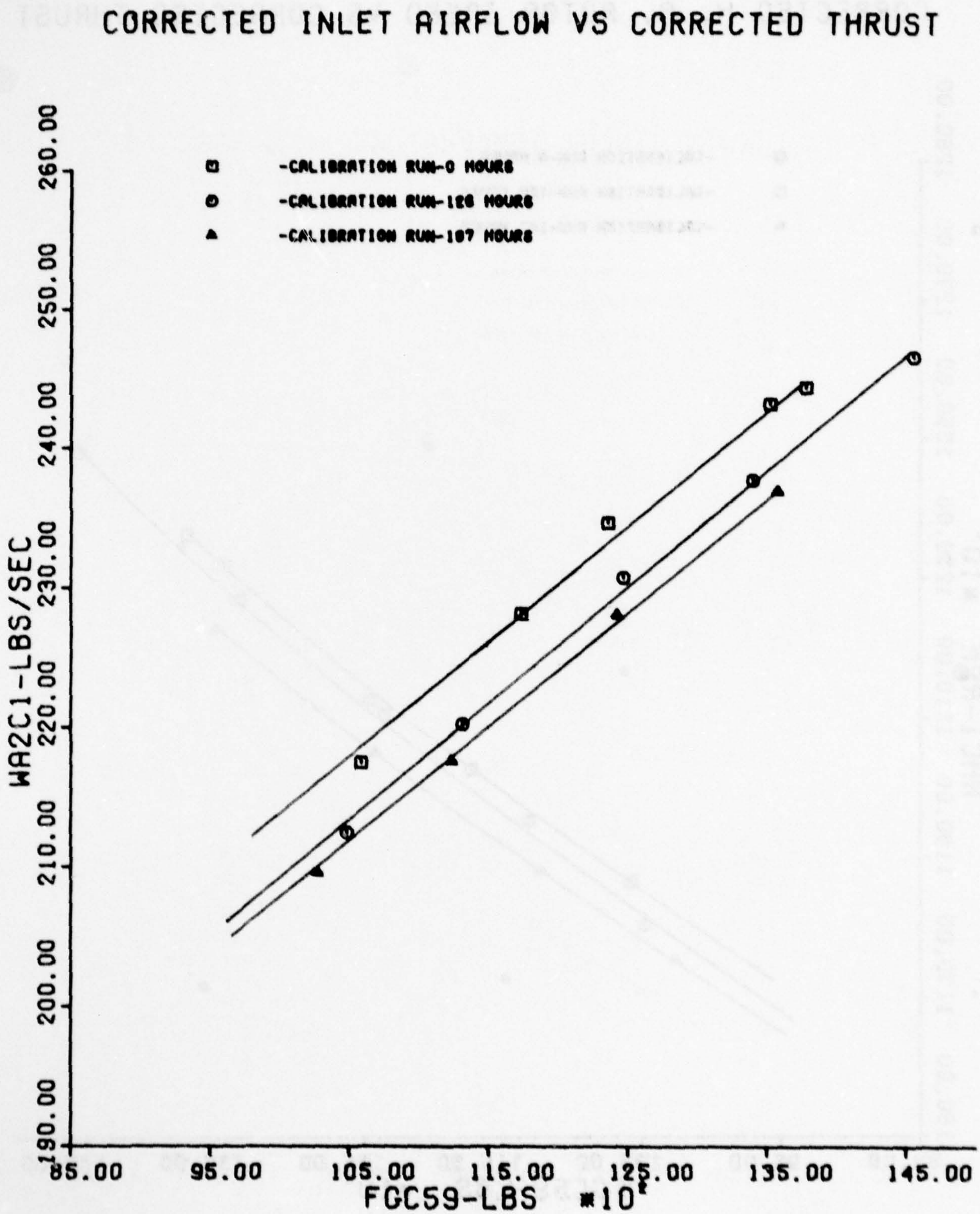


FIGURE 24 - CORRECTED INLET AIRFLOW VERSUS CORRECTED THRUST

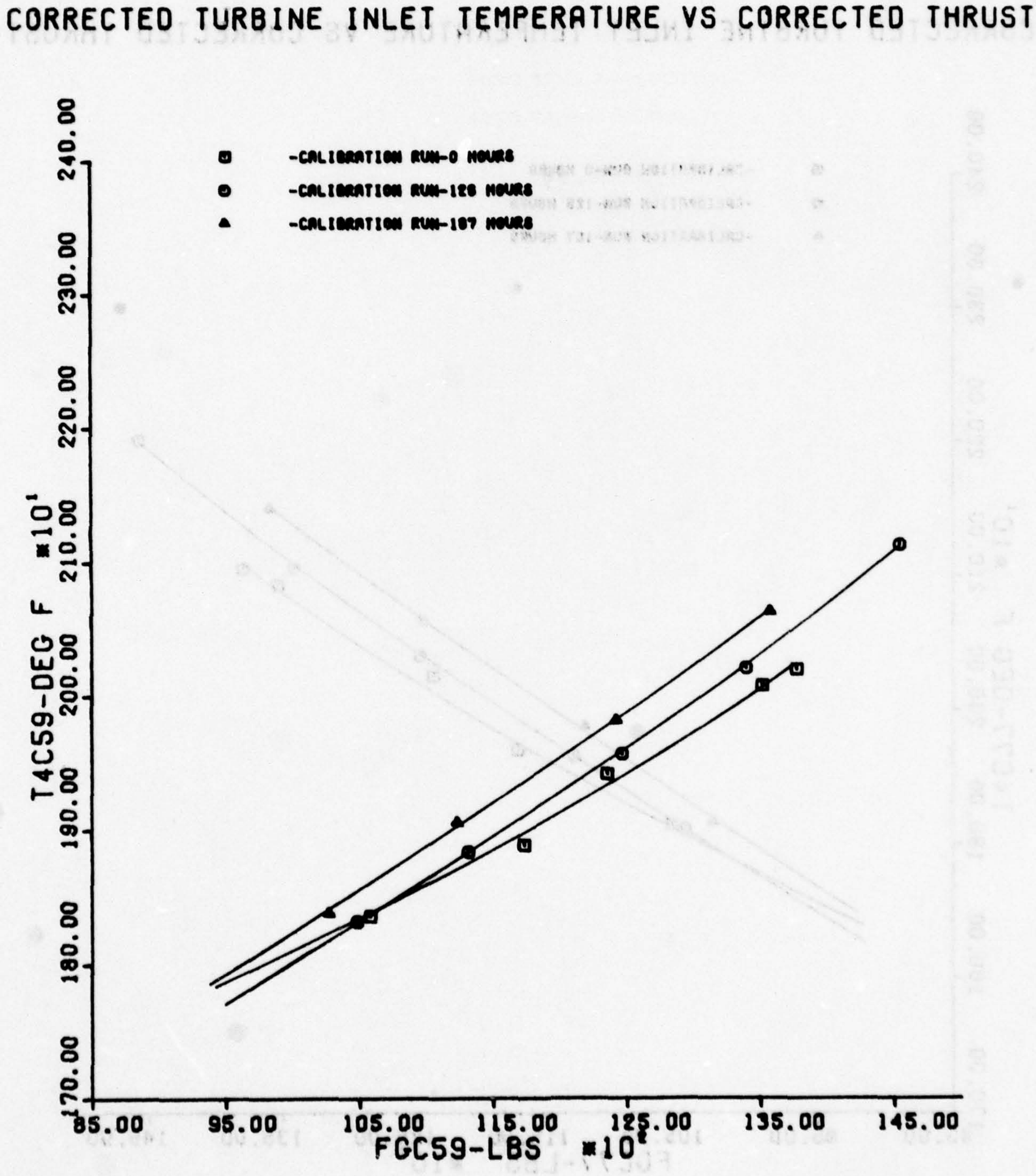


FIGURE 25 - CORRECTED TURBINE STATOR INLET TEMPERATURE VERSUS CORRECTED THRUST

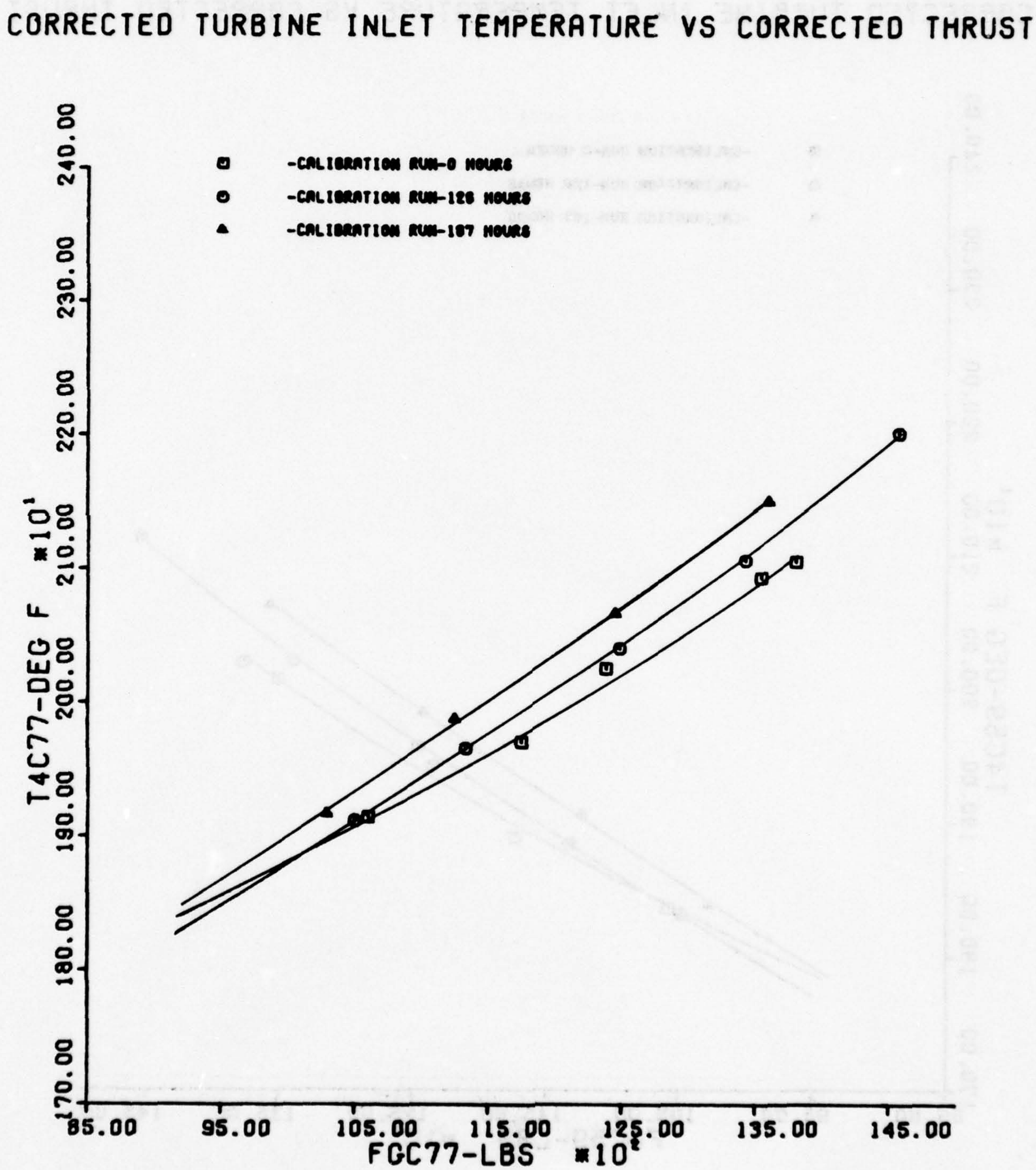


FIGURE 26 - CORRECTED TURBINE STATOR INLET TEMPLRATURE VERSUS CORRECTED THRUST

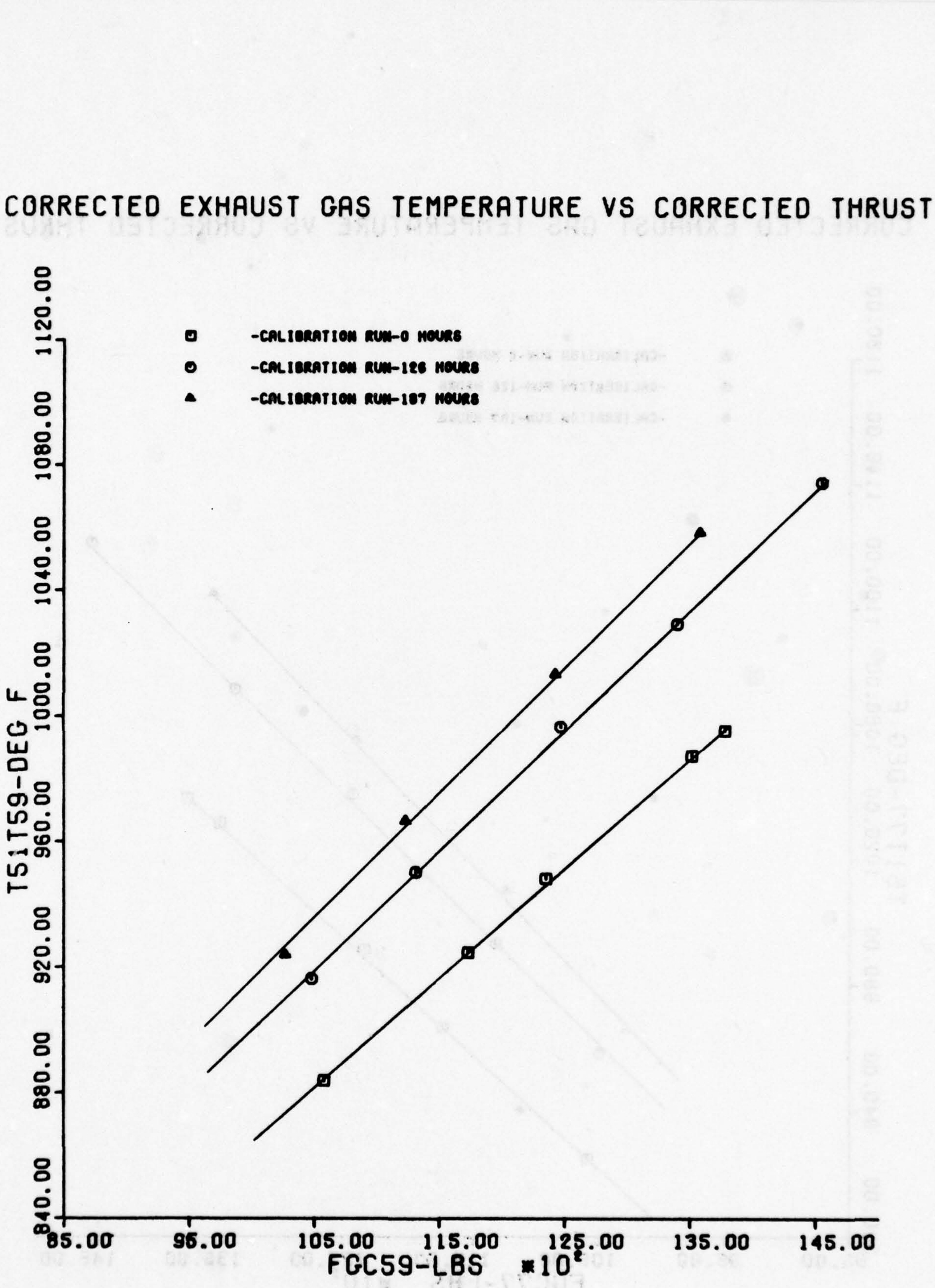


FIGURE 27 - CORRECTED EXHAUST GAS TEMPERATURE VERSUS CORRECTED THRUST

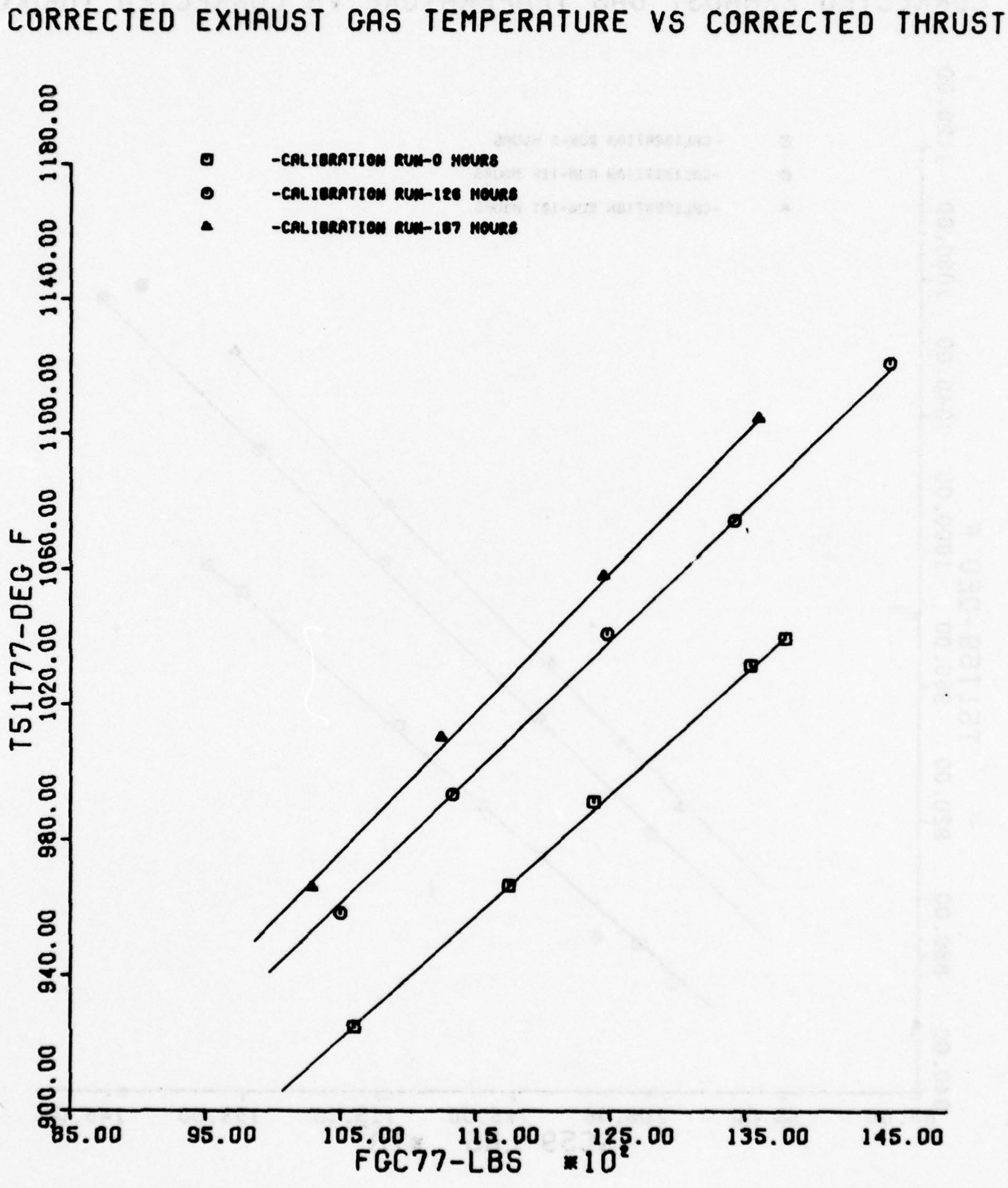


FIGURE 28 - CORRECTED EXHAUST GAS TEMPERATURE VERSUS CORRECTED THRUST

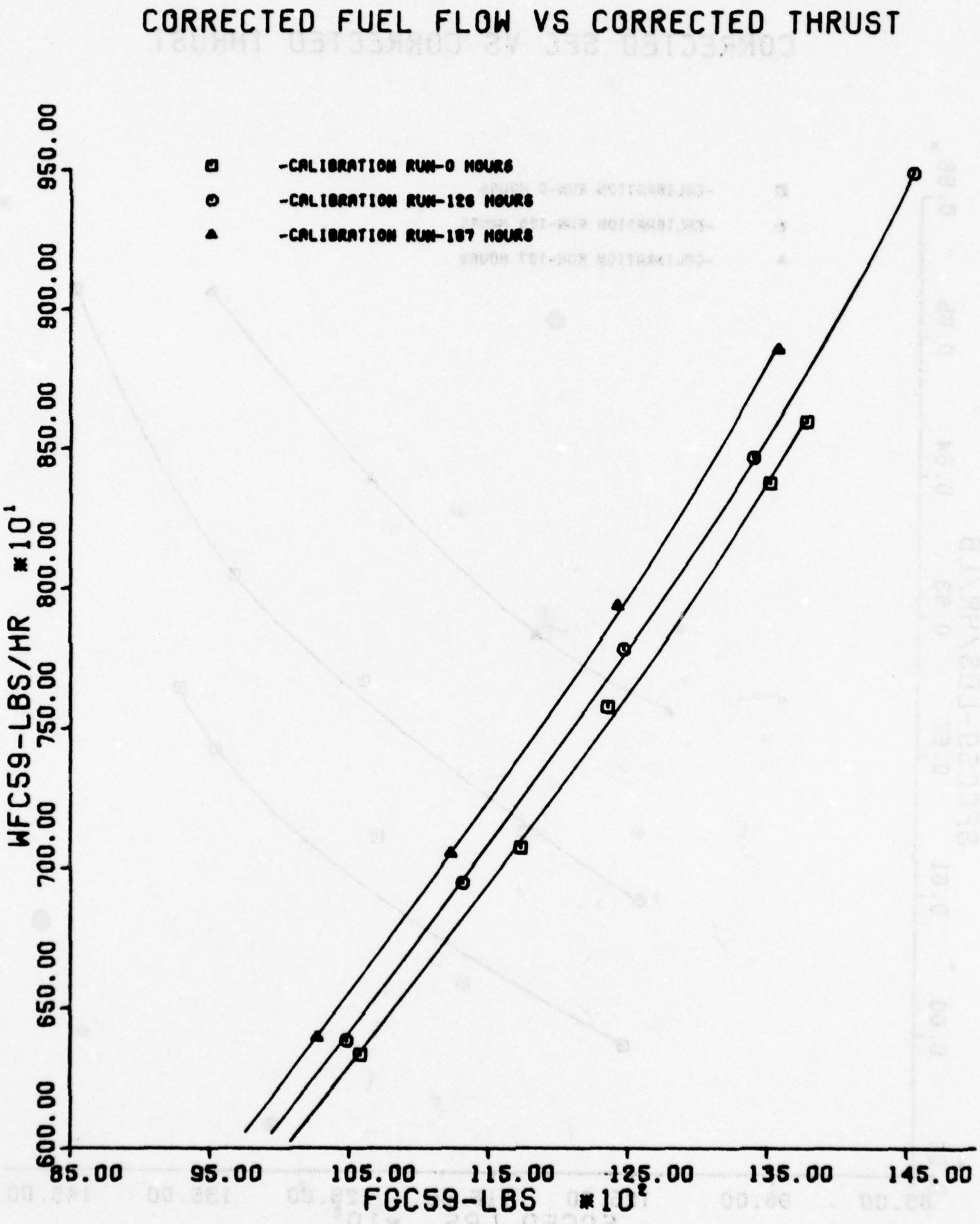


FIGURE 29 - CORRECTED FUEL FLOW VERSUS CORRECTED THRUST

CORRECTED SFC VS CORRECTED THRUST

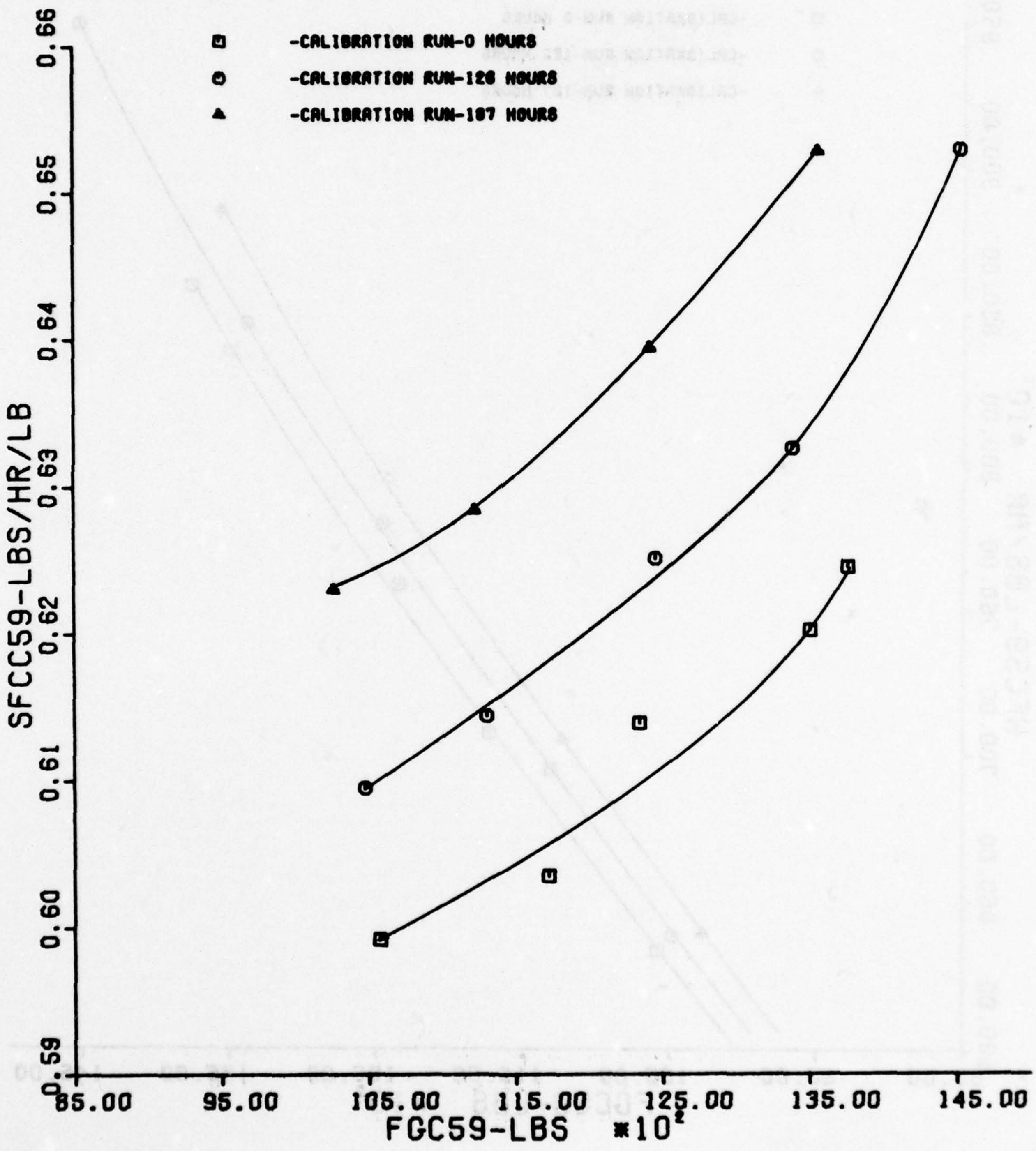


FIGURE 30 - CORRECTED SFC VERSUS CORRECTED THRUST

Parameter	0-126 Hours 13,500 Lb	0-126 Hours 11,000 Lb	126-187 Hours 13,500 Lb	126-187 Hours 11,000 Lb
Corrected Turbine Inlet Temp, T4C77	+1.6%	0	+1.0%	+1.4%
Corrected H.P. Rotor Speed, NHC1	- .2%	- .3%	- .7%	- .3%
Corrected Exhaust Gas Pres., P51C	+ .4%	+1.0%	+ .6%	- .3%
Corrected L.P. Rotor Speed, NLC1	+ .5%	+ .5%	- .4%	- .3%
Corrected Fuel Flow, WFC59	+2.4%	+1.7%	+2.9%	+2.7%
Corrected Airflow, WA2C1	-1.9%	-1.8%	-1.0%	-1.2%
Corrected Turbine Inlet Temp, T4C59	+1.5%	0	+1.0%	+2.4%
Corrected Exhaust Gas Temp, T51T59	+4.9%	+4.2%	+2.0%	+1.7%
Corrected Exhaust Gas Temp, T51T77	+4.8%	+4.2%	+2.1%	+1.9%

TABLE 5 CHANGES IN PERFORMANCE PARAMETERS WITH OPERATING TIME AT SELECTED THRUST LEVELS

VIII ANALYSIS OF POWER CALIBRATION DATA

Due to the severity of typical AMT cyclic testing, the amount of internal engine instrumentation is usually limited to the sensors which are required for control inputs and have been structurally designed to last in the rather severe environment associated with realistic engine operation (i.e., many cycles and long times at high temperature). In addition, the philosophy of AMT testing dictates that the test engine configuration match a field engine as near as possible, which again precludes the use of additional internal engine instrumentation. Normal TF41 AMT test procedures call for some additional instrumentation during the steady-state power calibrations performed periodically during the test program. Fan discharge and intermediate pressure compressor discharge temperature and pressure probes are inserted in the appropriate borescope ports, which along with the other instrumentation allows a complete definition of each compression component's performance. Unfortunately this instrumentation was not available for this test. In lieu of this internal engine instrumentation, a TF41 computer simulation was used in conjunction with the available part power calibration test data in an attempt to infer changes in internal engine operation as it accumulated more and more running time.

The computer model used in this exercise was Allison's TF41 production engine deck number B17B, dated 1 Sep 1977. This deck represents the steady-state performance of an average production TF41-A-1 engine, based on extensive performance testing at AEDC. This computer model was especially appropriate because it allowed input of efficiency and flow modifiers on each component's performance so that it was possible to adjust the cycle performance. Thus, the model can be set up to match the pre-test engine performance and then the component performance modifiers can be set to match the post-test engine power calibration data. Once accurate representations of the

engine's performance at these two points in time have been made, then changes in important engine performance parameters which could not be measured during the test can be inferred from the model. In this way, a better understanding of the deterioration characteristics of this engine can be gained.

It should be stressed at this point that it is nearly impossible to predict with <u>absolute</u> certainty and accuracy what is happening to each engine component as the engine deteriorates using the computer model. An obvious problem with this approach is that the engine tested was not a production TF41 but was equipped with aircooled second stage turbine blades for which the model does not account. However, the .5% additional cooling air and other design changes associated with it were felt to have minimal effect on the corrected performance parameter trends. Furthermore, scatter is induced in the test data due to measuring and recording inaccuracies. This scatter makes it impossible for the model to match the test data with 100% accuracy. Thus, differences between the test data and model predictions due either to data scatter or a fundamental simulation inaccuracy cannot be separated. Finally, the deck allows input of 10 different performance modifiers (efficiency and flow on each component). Changing the individual component performance characteristics to match the overall engine performance test data does not guarantee that the correct component performance has been degraded the correct amount. However, even though the absolute accuracy of this approach is somewhat suspect, it is felt that the pre-test and post-test models of engine performance that were developed are good enough to predict the direction and order of magnitude of the changes in some important engine parameters which could not be measured during this test.

The data used to check the accuracy of the computer models comes from the pre-test and post-test power calibration data initially discussed in Section VII and presented again in Figures 31 through 36 (0 hours and 187 hours). The engine was also run

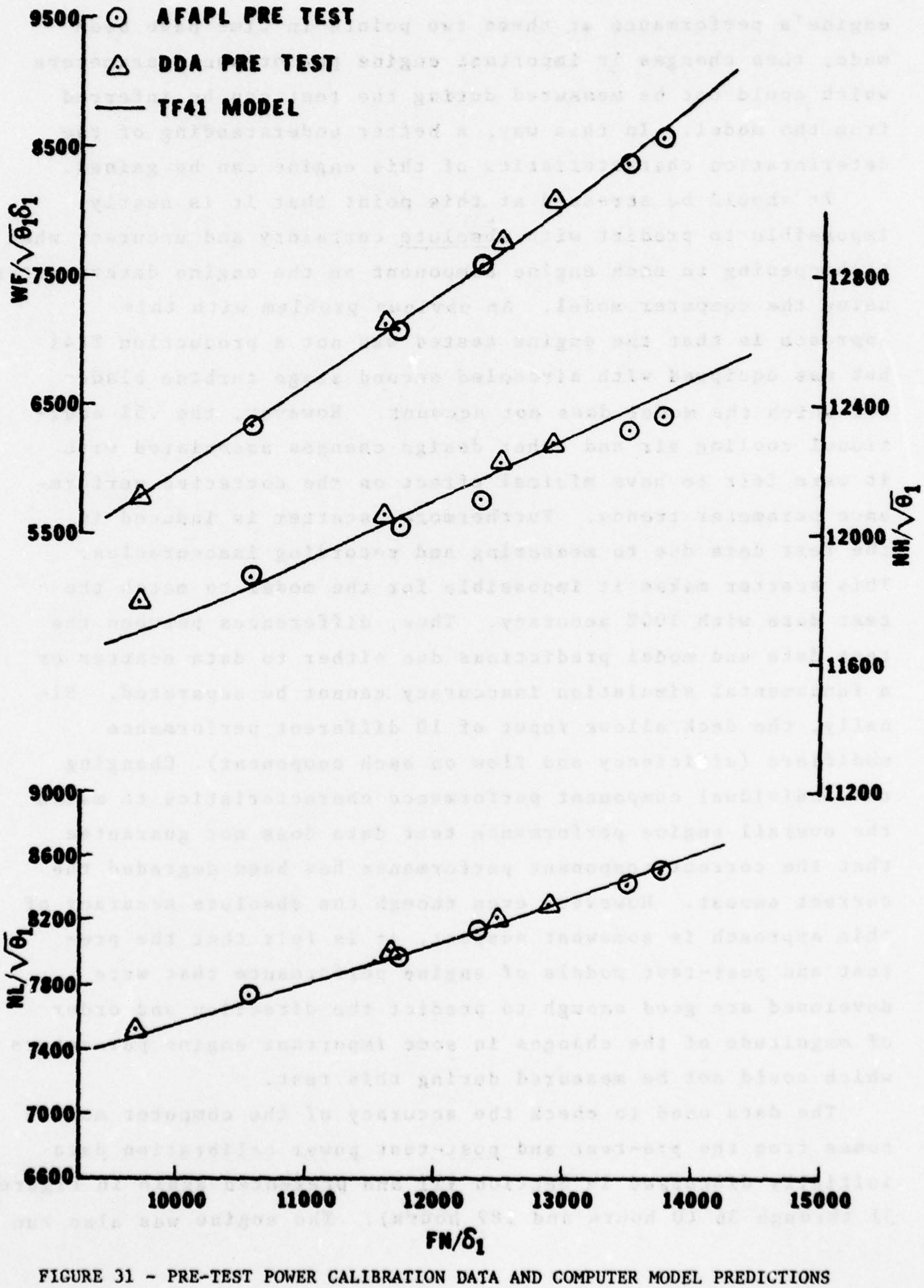


FIGURE 31 - PRE-TEST POWER CALIBRATION DATA AND COMPUTER MODEL PREDICTIONS

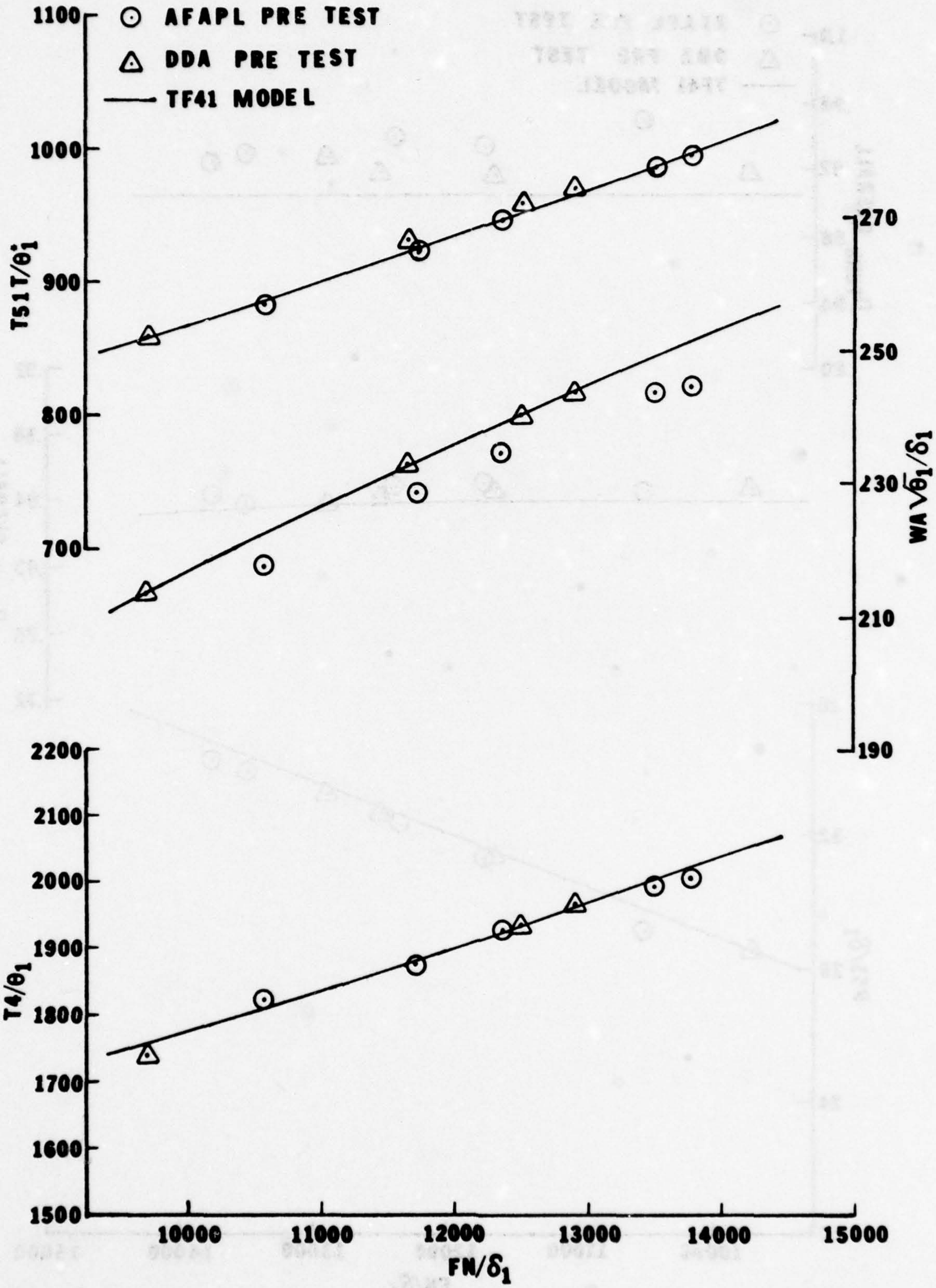


FIGURE 32 - PRE-TEST POWER CALIBRATION DATA AND COMPUTER MODEL PREDICTIONS

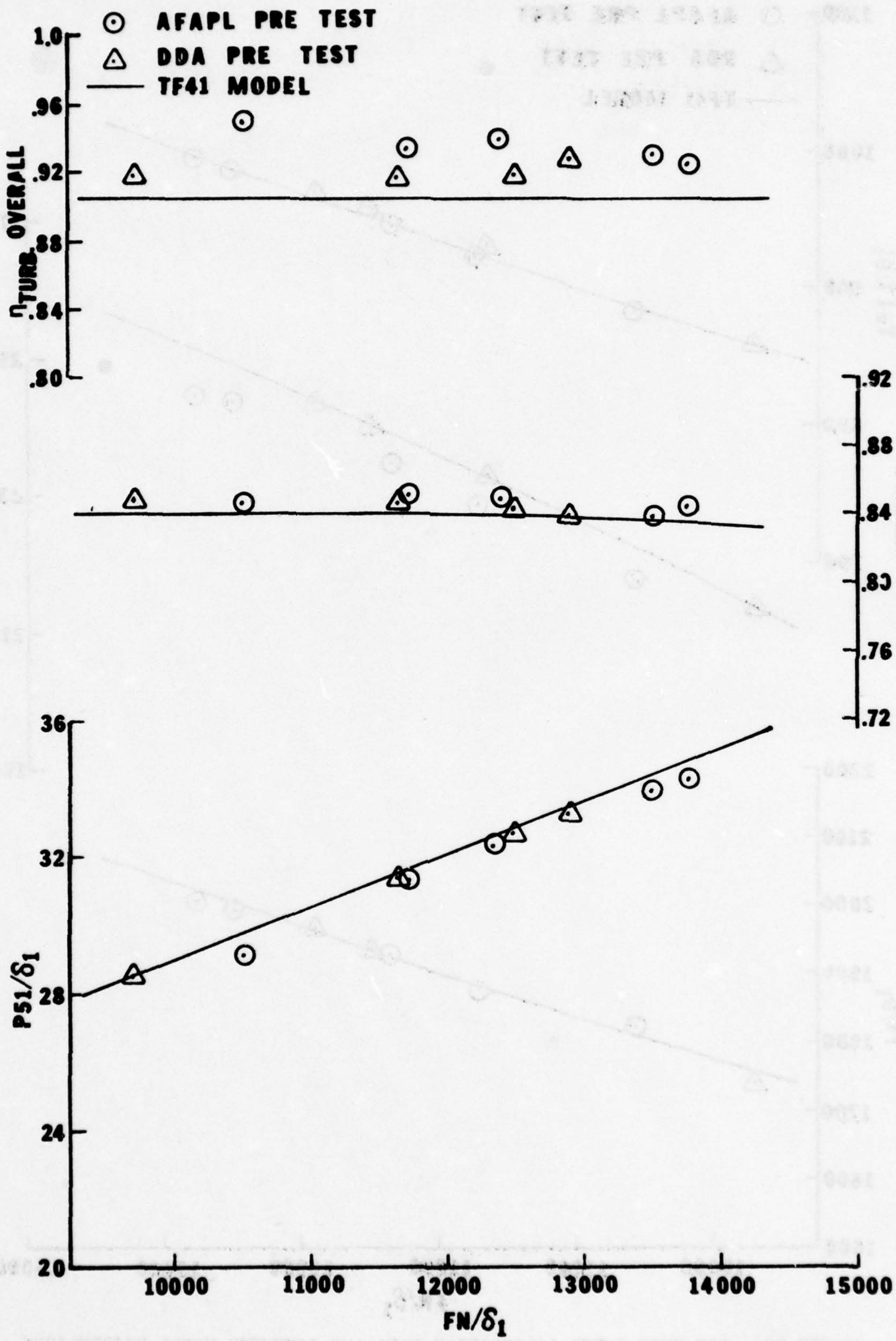


FIGURE 33 - PRE-TEST POWER CALIBRATION DATA AND COMPUTER MODEL PREDICTIONS

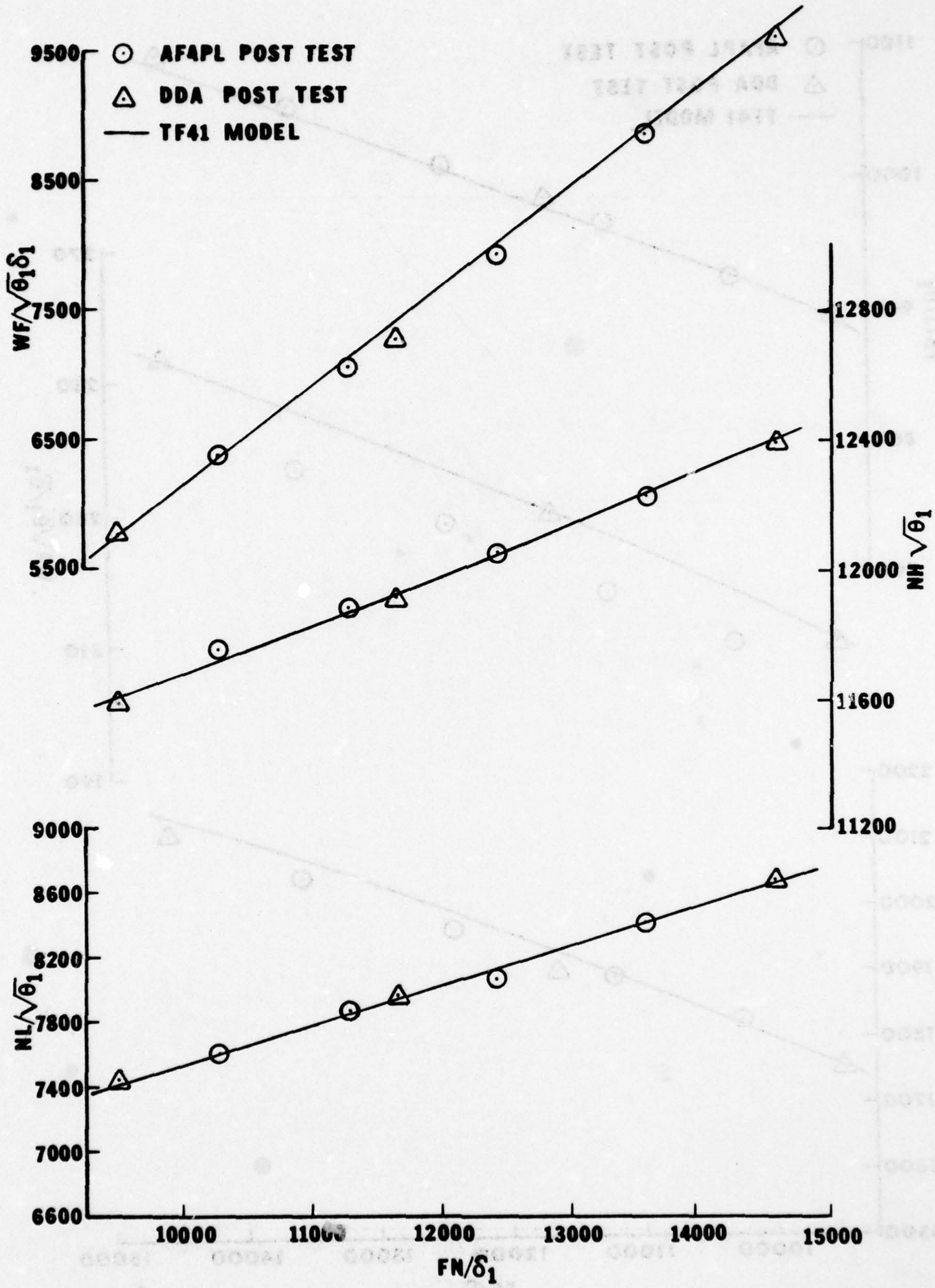


FIGURE 34 - POST-TEST POWER CALIBRATION DATA AND COMPUTER MODEL PREDICTIONS

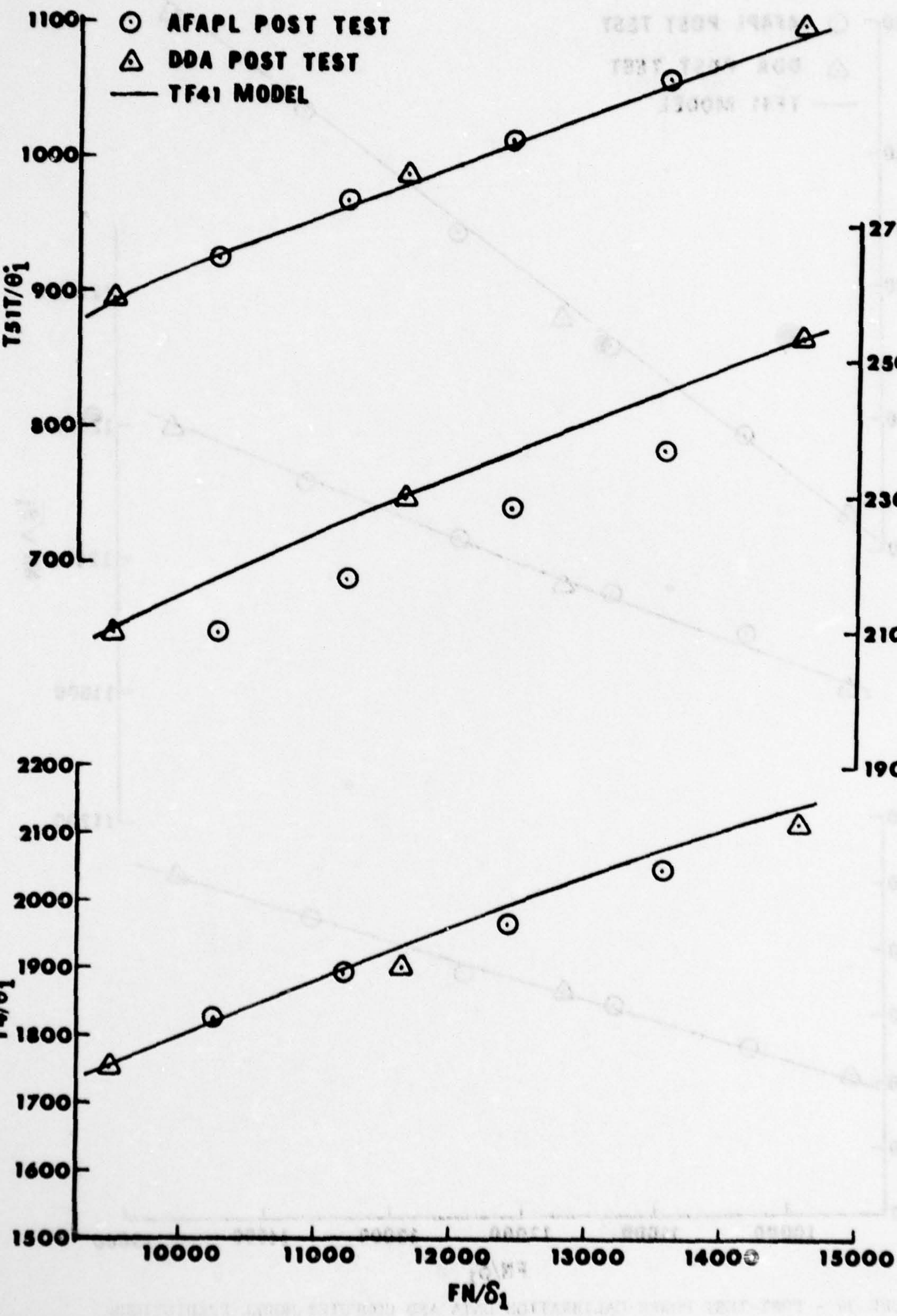


FIGURE 35 - POST-TEST POWER CALIBRATION DATA AND COMPUTER MODEL PREDICTIONS

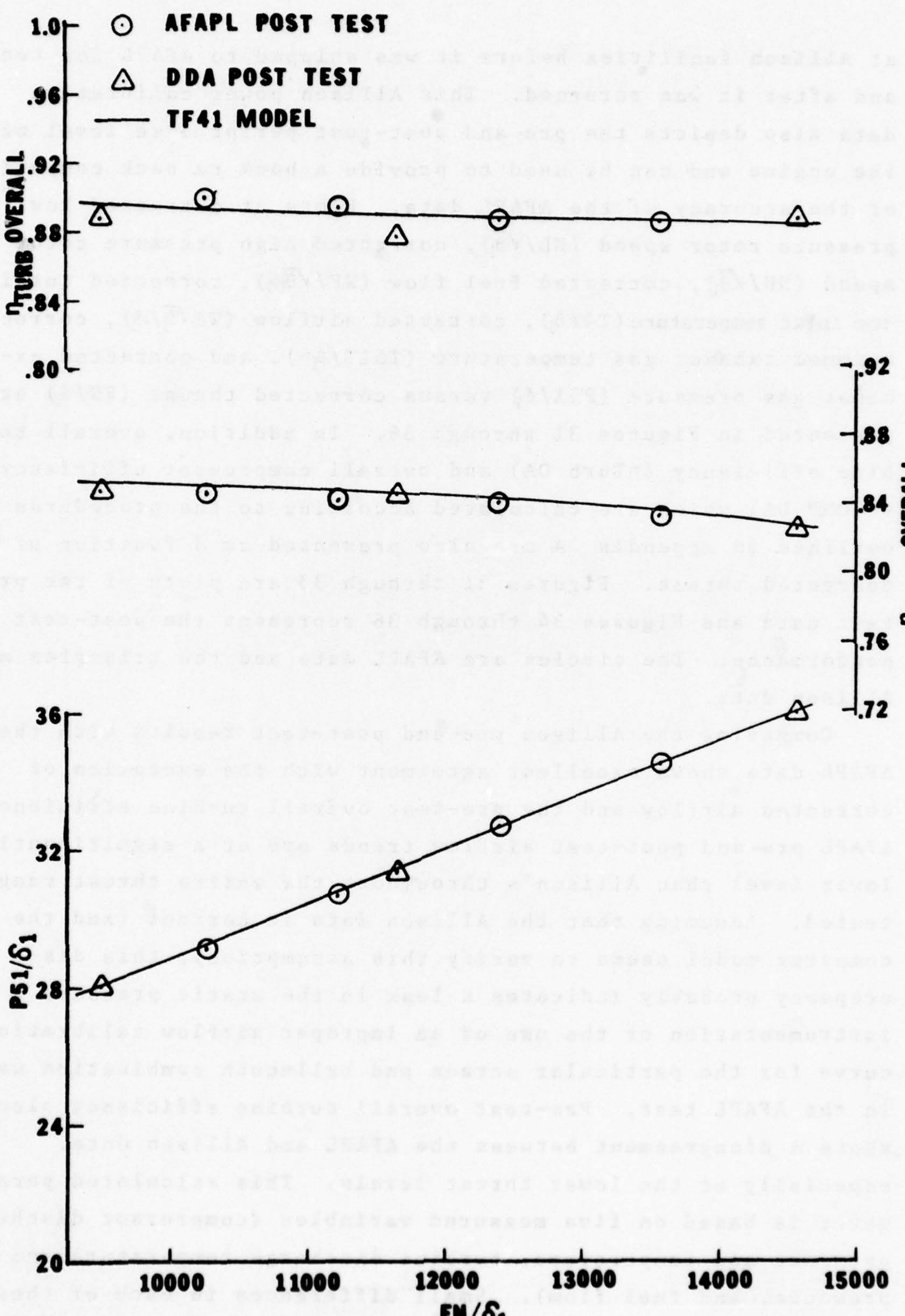


FIGURE 36 - POST-TEST POWER CALIBRATION DATA AND COMPUTER MODEL PREDICTIONS

at Allison facilities before it was shipped to AFAPL for testing and after it was returned. This Allison power calibration data also depicts the pre- and post-test performance level of the engine and can be used to provide a back to back comparison of the accuracy of the AFAPL data. Plots of corrected low pressure rotor speed ($NL/\sqrt{\theta_1}$), corrected high pressure rotor speed ($NH/\sqrt{\theta_1}$), corrected fuel flow ($WF/\sqrt{\theta_1}\delta_1$), corrected turbine stator inlet temperature ($T4/\theta_1$), corrected airflow ($WA\sqrt{\theta_1}/\delta_1$), corrected trimmed exhaust gas temperature ($T51T/\theta_1{}^*$), and corrected exhaust gas pressure ($P51/\delta_1$) versus corrected thrust (FN/δ_1) are presented in Figures 31 through 36. In addition, overall turbine efficiency (ηTurb OA) and overall compressor efficiency (ηCOMP OA) which are calculated according to the procedures outlined in Appendix A are also presented as a function of corrected thrust. Figures 31 through 33 are plots of the pre-test data and Figures 34 through 36 represent the post-test performance. The circles are AFAPL data and the triangles are Allison data.

Comparing the Allison pre- and post-test results with the AFAPL data shows excellent agreement with the exception of corrected airflow and the pre-test overall turbine efficiency. AFAPL pre- and post-test airflow trends are at a significantly lower level than Allison's throughout the entire thrust range tested. Assuming that the Allison data is correct (and the computer model seems to verify this assumption), this discrepancy probably indicates a leak in the static pressure instrumentation or the use of an improper airflow calibration curve for the particular screen and bellmouth combination used in the AFAPL test. Pre-test overall turbine efficiency also shows a disagreement between the AFAPL and Allison data, especially at the lower thrust levels. This calculated parameter is based on five measured variables (compressor discharge pressure and temperature, turbine discharge temperature and pressure, and fuel flow). Small differences in each of these parameters could result in a magnified effect on the calculated parameter. It should also be pointed out that it is impossible

to break out the temperature drop in the high pressure turbine due to the addition of cooling flow. This effect is bookkept in the definition of overall turbine efficiency and results in a value higher than one would expect to see. Again, though, the change in this variable from the pre-test to the post-test calibration is more important in this analysis than the absolute level of performance. The deviation in the trends of the other parameters was less than 1%. The differences in the pre-test maximum power thrust level is due to different inlet temperature conditions. AFAPL's calibration was run at 79°F and Allison's was run at 90°F. A difference in post-test maximum power thrust level exists because Allison allowed the engine to exceed its normal temperature limit (T51T = 1067°F) during their power calibration. This combination of Allison and AFAPL pre- and post-test power calibration data became the performance target to match using the available flexibility of the TF41 computer model.

The computer simulation predicted pre-test performance is shown by the solid line in Figures 31 through 33. The model was run at the same inlet conditions as the AFAPL calibration runs. The major problem with the computer model appears to be that it tends to underpredict the pre-test overall turbine efficiency by about 1.5% to 3%. The corrected airflow prediction did not agree with the AFAPL data but the Allison data fell exactly on the model prediction. Other than that, the simulation and the pre-test performance data agree to within about 1% accuracy. This particular cycle match was achieved by reducing the design turbine flow function by about 1.5% which reflects the fact that engine S/N 141677 was fitted with "bullnose" first stage turbine vanes which have about a 1.5% smaller flow area than a standard set of production vanes. All other engine parameters were left at production engine levels.

The solid line on Figures 34 through 36 compare the adjusted computer model predicted performance trends and the actual post-test calibration data. Once again, the model predictions

and the actual test data agree very closely. The corrected airflow prediction did not agree with the AFAPL data but again the Allison data fell exactly on the model prediction. At high thrust levels, the model tended to overpredict corrected turbine inlet temperature by about 1.5%. The correlation of the other variables were all within 1%. In order to achieve this cycle match with the TF41 simulation, the following modifiers had to be input in order to degrade performance below design levels: a 2% reduction in overall turbine efficiency, a .5% reduction in core compressor efficiencies, a 1.5% reduction in fan flow at a given corrected speed, and a .5% reduction in core flow at a given corrected speed. These changes in flow characteristics are somewhat arbitrary but they are necessary in order to force the model to match the post-test performance calibration data. It should be pointed out that these changes in flow are not simply shifts in operating line but are shifts in speed lines. In other words for any given corrected speed the compressors in the deteriorated engine pass less corrected flow than design. This change in pumping characteristics for the compressors could possibly have been the result of the oil leak which pumped oil into the gas path ahead of the second fan stage and coated all the downstream compression components. (see section IX).

Apparently, the major cause for performance deterioration as the TF41 accumulates running time is a substantial reduction in turbine efficiency which is probably the result of the abnormal turbine tip seal wear discussed in section IX. The test data shows nearly a 4% loss in overall turbine efficiency (the model indicates somewhat less). With this particular engine, overall compressor efficiency did not change very significantly showing only about a .5% loss after 187 operating hours. With the basic TF41 computer simulation predicting the pre-test performance and the simulation with the appropriate performance modifiers predicting the post-test engine performance trends, it is now possible to infer changes, as the engine deteriorates, in other important internal engine performance parameters which could not be measured directly.

The effects of deterioration on the cycle match can best be understood by initially comparing the operating characteristics of a deteriorated and undeteriorated engine at a constant turbine inlet temperature and assuming operation with a choked nozzle and no control system constraints. The degradation in turbine performance causes a reduction in available work at a constant turbine pressure ratio. The deteriorated turbine can no longer extract the necessary energy to drive the compressors to the same speeds as an undeteriorated engine. Consequently, both the low pressure and high pressure rotors must unwind to lower speeds.

It has been established that a deteriorated engine will run at lower speeds for the same turbine inlet temperature than an undeteriorated engine. Conversely, for the same speeds, the undeteriorated engine will have a lower turbine temperature. However, the deterioration caused speed change will force the engine to follow an operating line which is different than the design operating line.

In order to understand the direction of the operating line shift on the fan, assume that both engines (deteriorated and undeteriorated) can be run at a part power setting that results in the same corrected inlet fan flow. This would occur at nearly the same corrected speed but not necessarily at the same power setting. At this condition, the exhaust gas temperature for the deteriorated engine will be higher because turbine inlet temperature will be higher. A higher nozzle pressure is required in order to choke the fixed area exhaust nozzle with a higher exhaust gas temperature but the same total fan flow. Remembering that for a mixed flow engine, fan exit pressure and nozzle pressure are nearly the same, a higher nozzle pressure is the same as back pressuring the fan away from its normal operating line to a higher pressure. Thus, in addition to reduced speed, deterioration results in reduced fan surge margin.

A similar deterioration caused rematch takes place on the high pressure compressor. Assume that both the deteriorated and the undeteriorated engines could be run at power settings

that would result in equal high pressure compressor corrected inlet airflow. At this condition, the deteriorated engine would be running at a higher turbine inlet temperature due to the reduced turbine performance capability. In order to choke the high pressure turbine nozzle with the higher turbine inlet temperature but the same flow requires the deteriorated engine to have a higher pressure. Again this is the same as back pressuring the high pressure compressor away from its normal operating line to a higher pressure ratio. Thus, deterioration also causes a reduction in high pressure compressor surge margin.

The deteriorated operating point on the intermediate pressure compressor is somewhat more difficult to rationalize. It appears possible that the direction of the operating line shift is dependent on the magnitude of the performance deterioration in other components. With this particular engine the modified computer simulation predicted that deterioration resulted in a higher operating line than design. It has already been established that the high pressure compressor in the deteriorated engine is matched along a higher operating line. Therefore, it pumps less corrected flow at any given corrected speed because of the slope of the speed lines. The intermediate pressure compressor corrected flow must also be reduced. This compressor can not readily change speeds to reduce exit corrected flow since its corrected speed is determined by the fan operating point (speed and discharge temperature). Therefore, it must run at a higher pressure ratio than the equivalent undeteriorated intermediate pressure compressor running at the same corrected speed in order to reduce exit corrected flow to match the high pressure compressor inlet requirements.

The exact rematch of the engine due to deterioration will depend on satisfying the speed and work balances between the compressors and turbines and maintaining the static pressure balance at the mixing plane. The estimated rematch on the compression system components after 187 engine operating hours based on the TF41 computer simulation is shown graphically in figure 37.

In summary, comparison of the pre-test and post-test performance calibration data indicates a 4% loss in overall turbine efficiency and a .5% loss in overall compressor efficiency after 160 hours of AMT testing (187 hours of total operating time). Manipulations of the TF41 computer model to match the post-test power calibration data indicates that the fan airflow pumping characteristics have been reduced 1.5% and the core compressors have a .5% reduction in airflow relative to the pre-test performance. The computer simulation predicts that these losses in component performance due to engine deterioration translates, at constant turbine inlet temperature operation, into a 4% reduction in fan speed, a 2.5% reduction in high pressure rotor speed and new operating lines on all three compression components, matched closer to the surge line. Assuming that deterioration has not affected the design surge lines but has only shifted the operating lines, the fan loses approximately 7.5% of its design stall margin, the intermediate pressure compressor loses approximately 15% of its design stall margin and the high pressure compressor loses 13% of its design stall margin. These stall margin reductions are based on the design stall margins as predicted by the Allison TF41 computer simulation.

The post-test model estimates that the effect of this deterioration caused rematch on overall performance at intermediate power (assuming operation on a T51 limit and no change in trim resistor) is a 10% reduction in net thrust and a 4% increase in specific fuel consumption relative to the undeteriorated engine. It should be reiterated that these are estimates based on a TF41 production engine deck which has been somewhat arbitrarily modified to match the post-test performance data as close as possible. Another important point to keep in mind is that these deterioration characteristics may be more severe than a typical operational TF41 due to the oil leak which allowed a considerable amount of oil to enter the gas path and coat the downstream components as well as the excessive wear of the non-standard turbine tip seals. Caution should be used in attempting to apply this data to all TF41's in general.

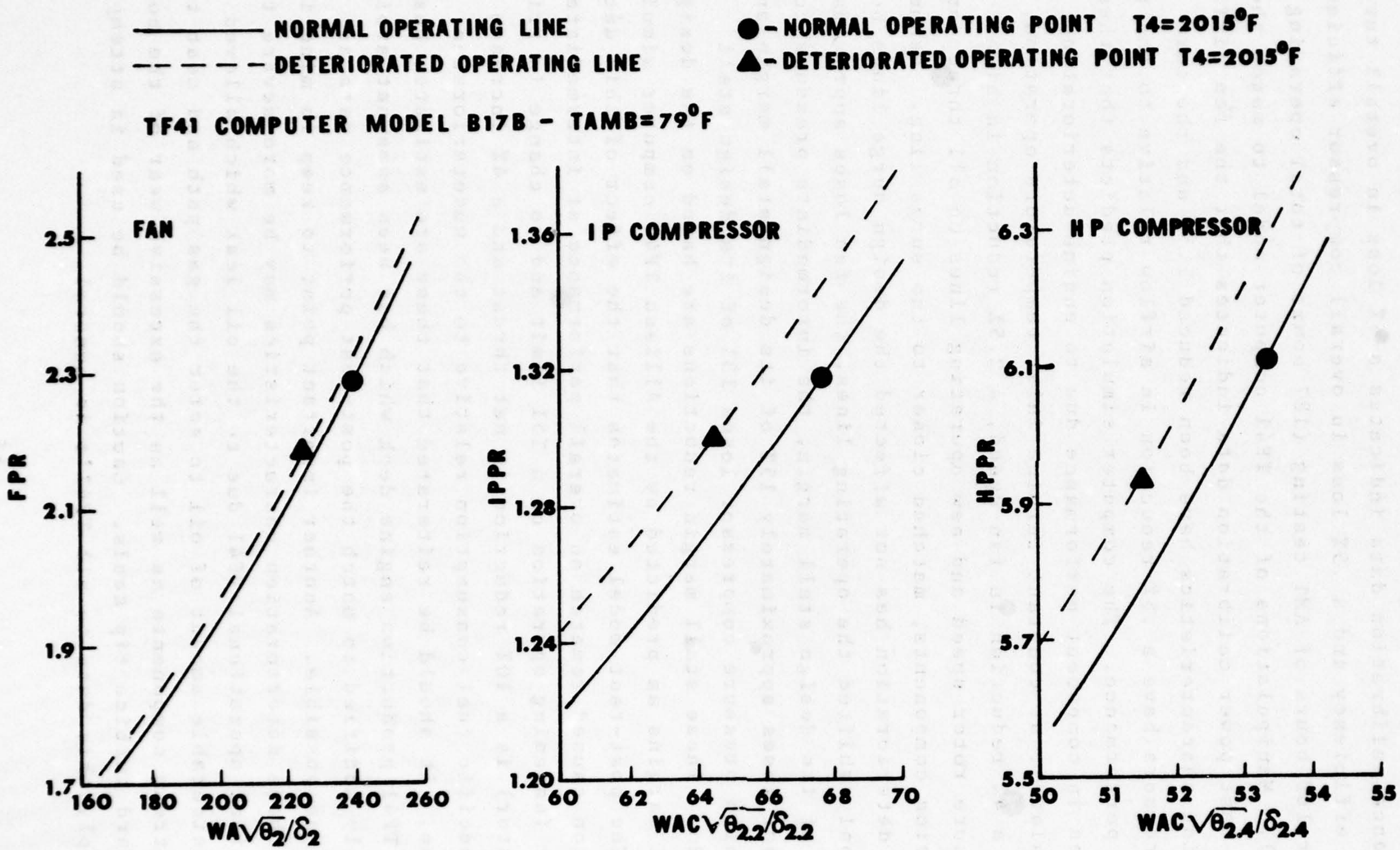


FIGURE 37 - EFFECT OF DETERIORATION ON ESTIMATED COMPRESSION SYSTEM OPERATING LINES

IX RESULTS OF TEARDOWN INSPECTION

The pertinent result of any accelerated mission test is the condition of the hardware, not only the specific parts that were being tested (in this case, the aircooled second stage turbine blades) but every part in the engine. After completing 160 hours of AMT testing, engine S/N 141677 was returned to Allison for a complete teardown and inspection. The detailed teardown and inspection report for the high pressure turbine section of the engine is contained in Appendix C.

The following is a list of part discrepancies which were discovered during the teardown of engine 141677:

- four combustor primary air scoops had crack indications and the scoop at the #5 position had failed in three pieces
- four combustion liners had worn thru inner connectors
- the accessory mounting bracket assembly was failed in two pieces
- a front compressor support vane was cracked at a previous weld repair
- the first stage high pressure turbine bullnose vanes had indications of weld cracks and erosion
- the second stage low pressure turbine nozzle vane support had indications of excessive wear in the vane locating slots and on the front flange of the vane retention groove
- the second stage high pressure turbine honeycomb tip seals had indications of excessive wear of the honeycomb
- six second stage high pressure turbine aircooled blades had crack indications at the tip of the leading edge just below the shroud.

Except for the cracked second stage aircooled blades, most of these part failures and wear have been observed in the past and are considered normal.

The cracks which occurred in the four combustor primary air scoops have been observed during TF41 engine overhaul. Investigation of this problem was initiated in 1975. The effort was terminated at the end of 1975 at Air Force's request because it was felt that the cracks were not serious enough to warrant further work. A failed air scoop has only been reported two other times during the entire TF41 program. However, Allison feels that no corrective action is necessary at this time.

The fretting wear of the combustion liner inner connectors has been observed in the past on both overhaul and development engines. Allison is working the problem in a program which is directed toward the investigation of wear-resistant coatings, increased thickness components, and monitoring of wear rates in AMT tests to improve the service life of the combustion components.

The front compressor support vane crack has also been observed on both overhaul and development engines. Allison proposed a program to investigate this type of failure for 1978 and 1979 but it has been deferred. At present, Oklahoma City Air Logistic Center (OCALC) has implemented their own repair procedure. This failure was the probable cause of the high oil consumption observed during this test. Oil is pumped through this vane to the front bearing. With the failure, under pressure some oil was pumped through the crack and out into the gas path.

The second stage high pressure turbine honeycomb tip seals are development pieces and are not expected to become production. These were installed in this engine to take up clearance due to worn tip seals on the second stage high pressure turbine blades. These were the only blades available for this engine build. The excessive seal wear increased tip clearance which was probably the major contributor to the significant deterioration in turbine efficiency that became apparent during the test.

The second stage low pressure turbine nozzle vane support wear has been observed before on high time hardware. Allison submitted an engineering change proposal to incorporate Metco spray coating on new production hardware to minimize fretting. The proposal was approved on 25 March 1975 as a repair procedure only and did not apply to new production.

The accessory mounting bracket assembly failure has occurred before. Since 1973, there have been 38 failures reported. Allison's investigation of the problem disclosed that the brackets were purchased by OCALC direct from the vendor. Excess material on the bracket base caused a bind when the bracket was installed. Subsequent operational stains caused the bracket to break. Brackets at Allison were found to be satisfactory.

Metallurgical analyses conducted by Allison concluded that the aircooled second stage turbine blades failed in facet fatigue originating on the convex suction side approximately .045 - .100 inch from the leading edge near the shroud. These cracks are of major concern. The fatigue life of these blades was originally estimated at nearly 2000 hours and this test was being run to help verify this estimate. The failures were discovered after only 160 AMT test hours. The metallurgical investigation further concluded that casting defects (i.e., inclusions, voids, or gas pockets) contributed to two of the six second stage blade failures. The cause of failures for the other four blades is still unknown.

However, the second stage blades in this engine were not new and had been subjected to nearly 500 major "go-go" cycles (1 major go-go cycle is composed of 8 idle to max to idle throttle transients) in an earlier test. At this time the blade shrouds were rubbed severely resulting in the loss of most of the shroud knife seals which were repaired prior to AMT testing. It is speculated, although not proven, that the damage significantly reduced the fatigue life of these blades and led to their premature failure.

X SUMMARY AND CONCLUSIONS

An accelerated mission test of a TF41-A-1 engine S/N 141677 was run at the Air Force Aero Propulsion Laboratory's "3" stand, sea level engine test facility. The objectives of this test were to establish the durability characteristics of a set of aircooled second stage turbine blades and to document overall engine performance deterioration under realistic usage conditions. The test was initially scheduled for 263 hours but was prematurely terminated after 160 AMT hours (187 total engine operating hours) due to the requirement for this engine in another AMT test.

A teardown inspection of the engine was performed at Allison. Several damaged or worn parts were found in the burner and turbine sections, although nothing major or unexpected. However, fatigue cracks were discovered in six of the aircooled second stage turbine blades. These blades failed well before the estimated fatigue life had been exceeded. An analysis of these blades to determine the probable cause of failure is currently ongoing at Allison. It has been determined that casting defects contributed to two of the blade failures. These blades were not new, and very preliminary results indicate that rub damage sustained during an earlier test may have substantially reduced the fatigue lives of the remaining four blades.

The operation of the engine during the test was characterized by very high oil consumption, well above tech order limits. The teardown inspection revealed that a weld repair in the front compressor support vane which ducts oil to the front bearing failed. This allowed oil to leak into the gas path.

The deterioration investigation consisted of tracking maximum thrust at constant engine inlet temperature as a function of engine operating time, comparing part power performance data obtained periodically during the test, and use of a TF41 production engine performance model. The test data showed that the engine lost between 7.5% and 8.5% in thrust at constant inlet temperature after about 125 engine

operating hours. The part power performance calibrations showed a 4% increase in specific fuel consumption after 160 AMT test hours. The data indicates that most of this loss in performance could be attributed to nearly a 3%-4% reduction in overall turbine efficiency.

A TF41 production engine steady-state performance computer simulation was used to analyze the pre- and post-test power calibration data to try to understand what was happening internally as the engine deteriorated. The approach was required due to a lack of internal engine instrumentation during this test. In addition to the 3%-4% loss in overall turbine efficiency that the test data showed, the model predicted that during the test, the fan lost about 1.5% in flow pumping capability at a given corrected speed, and the intermediate and high pressure compressors suffered about .5% reduction in corrected flow. This loss in flow passing capability most likely can be attributed to the oil leak which allowed oil to enter the gas path and coat the compression components. The significant deterioration in turbine performance was probably due to the increased clearances caused by the excessive wear of the second stage high pressure turbine honeycomb tip seals. The model also estimated that the deteriorated engine lost 7.5% of design fan surge margin, 15% of design intermediate pressure compressor surge margin and 13% of design high pressure compressor surge margin. Unfortunately, the oil leak and the excessive wear of the non-standard turbine tip seals may have been a major contribution to this engine's deterioration characteristics. It is therefore questionable if this deterioration data can be applied to a typical production TF41 in service.

APPENDIX A: PERFORMANCE CALCULATIONS

— SYMBOLS —

SYMBOL	NAME	SOURCE	UNITS
A4	Turbine Inlet Nozzle Area	Constant	IN^2
CPFG	Specific heat correction for thrust	Calculated	———
CPN	Specific heat correction for speed	Calculated	———
CPP3	Specific heat correction for P3	Calculated	———
CPP5	Specific heat correction for P5	Calculated	———
CPT3	Specific heat correction for T3	Calculated	———
CPT5	Specific heat correction for T5	Calculated	———
CPWA	Specific heat correction for airflow	Calculated	———
CPWF	Specific heat correction for fuel flow	Calculated	———
CVPFG	Humidity correction for thrust	Calculated	———
CVPN	Humidity correction for speed	Calculated	———
CVPP3	Humidity correction for P3	Calculated	———
CVPP5	Humidity correction for P5	Calculated	———
CVPT3	Humidity correction for T3	Calculated	———
CVPT5	Humidity correction for T5	Calculated	———
CVPWA	Humidity correction for airflow	Calculated	———
CVPWF	Humidity correction for fuel flow	Calculated	———
EPR	Engine pressure ratio	Calculated	———
FGM	Measured thrust	Measured	LB_F
FG	Thrust	Calculated	LB_F
H1	Engine Inlet Enthalpy	Table Look Up	BTU/LB_M
H3	Compressor Discharge Enthalpy	Table Look Up	BTU/LB_M
H3I	Ideal Compressor Discharge Enthalpy	Calculated	BTU/LB_M
H4	Turbine Inlet Enthalpy	Calculated	BTU/LB_M
H41	Turbine Rotor Inlet Enthalpy	Calculated	BTU/LB_M
H5	Untrimmed Exhaust Gas Enthalpy	Table Look Up	BTU/LB_M
H5I	Ideal Turbine Exit Enthalpy	Calculated	BTU/LB_M
HF4	Enthalpy of the Fuel	Table Look Up	BTU/LB_M
LHV	Fuel Lower Heating Value	Constant	BTU/LB_M
[illegible]	HP Rotor Speed	Calculated	RPM
[illegible]	Measured HP Rotor Speed	Measured	RPM

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NL	LP Rotor Speed	Calculated	RPM
NLM	Measured LP Rotor Speed	Measured	RPM
OPR	Overall Compressor Pressure Ratio	Calculated	____
PAMB	Ambient Pressure	Measured	IN HG
P1	Engine Inlet Total Pressure	Measured	IN H_2O
P3	Compressor Discharge Total Pressure	Calculated	PSIA
P4	Turbine Inlet Total Pressure	Calculated	PSIA
P5M	Measured Exhaust Gas Total Pressure	Measured	IN HG
P5	Exhaust Gas Total Pressure	Calculated	IN HG
PS1	Bellmouth Static Pressure	Measured	IN HG
PS3	Compressor Discharge Static Pressure	Measured	PSIA
RES	T5 Ballast Resistance	Constant	OHMS
RH	T5 Thermocouple Harness Resistance	Constant	OHMS
T1	Engine Inlet Total Temperature	Measured	^oF
T3M	Measured Compressor Discharge Total Temperature	Measured	^oF
T3	Compressor Discharge Total Temp.	Calculated	^oF
T4	Turbine Inlet Total Temperature	Calculated	^oR
T5M	Measured Trimmed Exhaust Gas Total Temperature	Measured	^oF
T5	Trimmed Exhaust Gas Total Temp.	Calculated	^oF
T5UT	Untrimmed Exhaust Gas Total Temp.	Calculated	^oF
TPR	Overall Turbine Pressure Ratio	Calculated	____
TJB	Junction Box Temperature	Measured	^oF
TJBS	Standard Junction Box Temp.	Constant	^oF
V_p	Vapor Pressure	Table Look Up	IN HG
WA	Engine Inlet Airflow	Calculated	LB_M/SEC
WA22	Engine Core Airflow	Calculated	LB_M/SEC
WA4	Turbine Inlet Airflow	Calculated	LB_M/SEC
WAI	Total Corrected Engine Inlet Airflow	Calculated	LB_M/SEC
WFM	Measured Fuel Flow	Measured	LB_M/HR
WF	Fuel Flow	Calculated	LB_M/HR
WG4	Turbine Inlet Gas Flow	Calculated	LB_M/SEC
ΔP	Bellmouth Pressure Differential	Calculated	IN H_2O
ΔP_B	Burner Pressure Drop	Constant	____
δ	Inlet Pressure Correction	Calculated	____

θ	Inlet Temperature Correction	Calculated	____
θ^*	Inlet Temperature Correction for T5	Calculated	____
η_C	Overall Compressor Efficiency	Calculated	____
η_B	Burner Efficiency	Constant	____
η_T	Overall Turbine Efficiency	Calculated	____

Correction of Measured Parameters

Most of the engine parameters measured during the test must be corrected for several different effects. These effects include the standard inlet temperature and pressure corrections as well as empirically derived corrections for humidity, specific heat, and instrumentation. The expressions for these correction factors were obtained from Technical Order 2J-TF41-3. The procedure for correcting the data is outlined below. Note that corrections can be made for a standard temperature of $59^{o}F$ or $77^{o}F$.

Inlet Condition Corrections

TSTD=518.7 or 536.7

$\theta \quad = T1/TSTD$

$\delta \quad = P1/14.696$

Humidity Corrections

$$HUM = 4353.2\left(\frac{V_P}{PAMB-V_P}\right)$$

CVPFG = 1.0 + .0000143 x HUM

CVPN = 1.0 - .0000343 x HUM

CVPWA = 1.0 + .0000457 x HUM

CVPWF = 1.0 - .0000814 x HUM

CVPP3 = 1.0

CVPP5 = 1.0 + .0000079 x HUM

CVPT3 = 1.0 + .00003 x HUM

CVPT5 = 1.0 - .0000264 x HUM

C_P Corrections

CPFG = 1.0 - .0001214 (T1-TSTD)

CPN = 1.0

CPWA = 1.0

CPWF = 1.0 - .0003846 (T1-TSTD)

$CPP3 = 1.0 - .0000645\ (T1-TSTD)$

$CPP5 = 1.0 - .000071\ (T1-TSTD)$

$CPT3 = 1.0 + .0001355\ (T1-TSTD)$

$CPT5 = 1.0 - .000071\ (T1-TSTD)$

Corrected Parameter Calculations

1. THRUST

$$\frac{FG}{\delta} = \frac{FGM \times CVPFG \times CPFG}{\delta}$$

2. FUEL FLOW

$$\frac{WF}{\delta\sqrt{\theta}} = \frac{WFM \times CVPWF \times CPWF \times \frac{LHV}{18400}}{\delta\sqrt{\theta}}$$

3. HIGH PRESSURE ROTOR SPEED

$$\frac{NH}{\sqrt{\theta}} = \frac{NHM \times CVPN \times CPN}{\sqrt{\theta}}$$

4. LOW PRESSURE ROTOR SPEED

$$\frac{NL}{\sqrt{\theta}} = \frac{NLM \times CVPN \times CPN}{\sqrt{\theta}}$$

5. HIGH PRESSURE COMPRESSOR DISCHARGE PRESSURE

$$\frac{P3}{\delta} = \{(\frac{PS3}{\delta} \times CVPP3 \times CPP3) + 4.56\} \times 1.0512$$

6. EXHAUST GAS PRESSURE

$$\frac{P5}{\delta} = \frac{P5M}{\delta} \times CVPP5 \times CPP5$$

7. HIGH PRESSURE COMPRESSOR DISCHARGE TEMPERATURE

$$\frac{T3}{\theta} = \{(\frac{T3M + 459.7}{\theta} \times CVPT3 \times CPT3) + 1.2\} \times 1.003 - 459.7$$

8. EXHAUST GAS TEMPERATURE

$$\frac{T5}{\theta^*} = (\{T5M \times (1.0 + \frac{RH}{RES})\} - (\frac{RH}{RES} \times TJB)$$
$$+\{459.7 \times (1.0 - \theta^*)\} + \{\frac{RH}{RES_S} \times \theta^* \times TJBS\})$$
$$\div (\{1.0 + \frac{RH}{RES}\} \times \theta^*)$$

where

$$\theta^* = \frac{\theta^{.8788}}{CVPT5 \times CPT5}$$

9. AIRFLOW

$$\frac{WA\sqrt{\theta}}{\delta} = WAI \times CVPWA \times CPWA$$

Calculations of Performance Variables

The following section presents the methods used to calculate some engine performance parameters from the temperatures and pressures measured during the test. The engine parameters that can be calculated include: total engine airflow, engine core airflow, turbine inlet temperature, bypass ratio, overall compressor efficiency, overall turbine efficiency, overall compressor pressure ratio, overall turbine pressure ratio and engine pressure ratio.

Total Engine Airflow

The inlet bellmouth has static and total pressure probes which are connected to manometer tubes in the test cell control room. Total pressure (gauge) is measured in inches of water and static pressure (gauge) is measured in inches of mercury. The parameter, $\Delta P/\delta$ is calculated from the difference in these manometer readings and used to enter the curve in Figure 38 to yield engine total corrected airflow. (This curve is from the bellmouth manufacturer and is only good for bellmouth number 6872762 and screen number 6872166 or 6798364.) This airflow must then be corrected for humidity and Cp effects as outlined earlier. The calculation of $\Delta P/\delta$ is:

$$\frac{\Delta P}{\delta} = \frac{P1 - PS1\ (13.596)}{\frac{P1}{29.92}} \qquad (1)$$

Turbine Inlet Temperature and Engine Core Airflow

The calculation of turbine inlet temperature and engine core airflow is an iterative calculation using measured fuel flow, measured compressor discharge pressure and temperature (appropriately corrected), turbine inlet nozzle flow area, and some assumed burner performance parameters. For the calculations summarized in this appendix, burner pressure drop was assumed to be .055 and burner efficiency was assumed at .999. The calculation procedure is as follows:

$$P4 = (1-\Delta P_B)P3 \qquad (2)$$

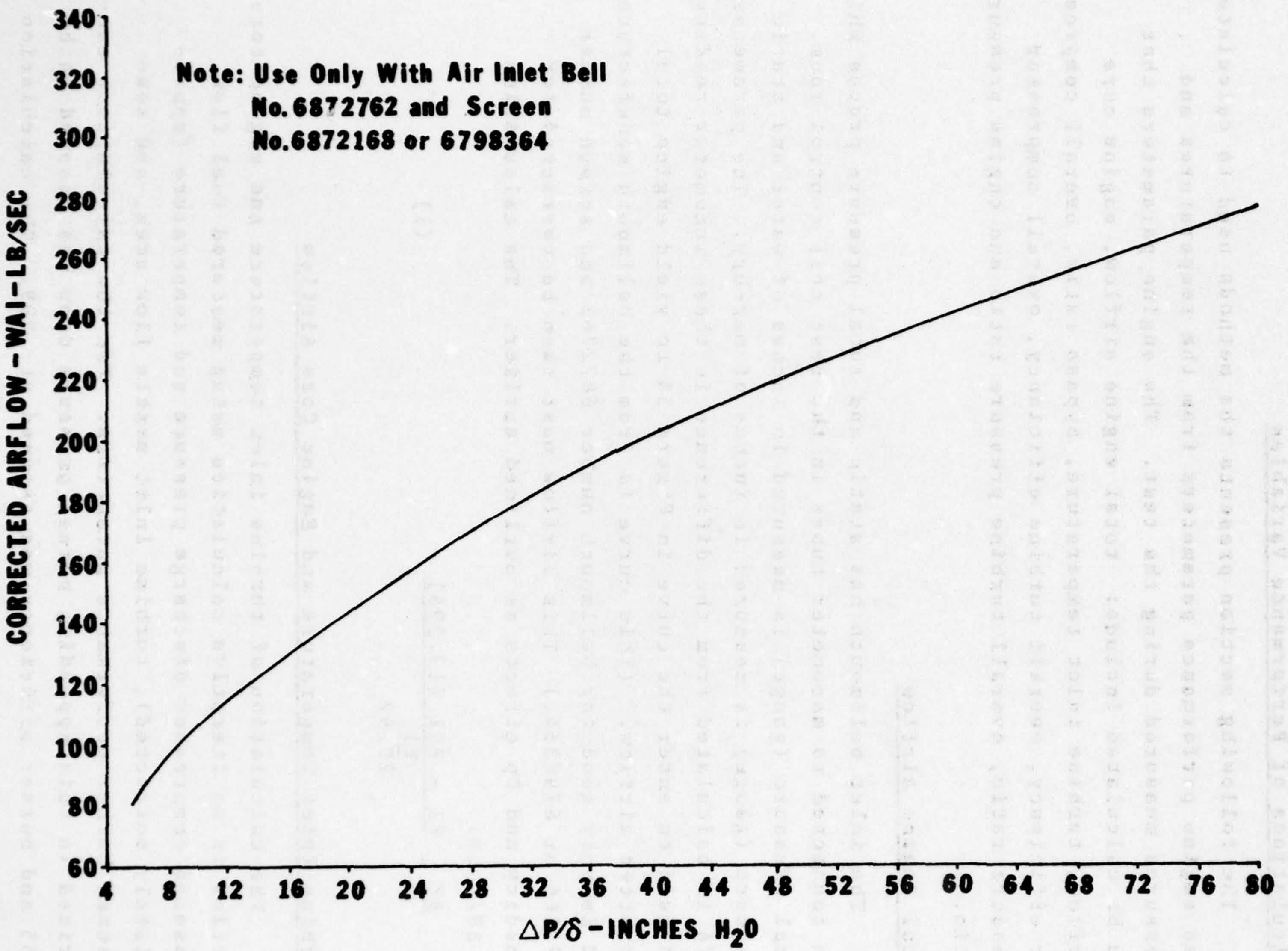

FIGURE 38 - INLET BELLMOUTH CHARACTERISTICS

Assuming that the turbine nozzle is choked:

$$\frac{WG4\sqrt{T4}}{P4\ A4} = \frac{.5312(\frac{LBm}{SEC})\sqrt{°R}}{LB_F} \qquad (3)$$

Substituting equation (2) into equation (3) yields:

$$WG4\sqrt{T4} = .5312(A4)\ (P3)\ (1 - \Delta P_B) \qquad (4)$$

The other governing equation in this case is the energy balance across the burner:

$$H4 = H3 + \eta_B\left(\frac{WF}{WA4}\right)\ (LHV + 182. - HF4) \qquad (5)$$

The procedure for solving these two simultaneous equations, noting

$$WA4 = WG4 - WF \qquad (6)$$

is to guess a T4 and calculate WG4 from equation (4). An H4 can then be calculated from equation (5). T4 can be obtained from the calculated H4 using thermodynamic tables. The entire procedure is then repeated until the guessed T4 and the T4 calculated from equation (5) are within 1^o. When this iteration converges, a solution is obtained for both T4 and WA4.

The engine core airflow (IP compressor inlet airflow) can then be calculated by adding the turbine cooling flow to the turbine inlet airflow and allowing .2% for leakage.

$$WA22 = \frac{WA4 + .0604\ WA4}{.998} \qquad (7)$$

Bypass ratio can then be calculated using the results of equation (7) and the previously calculated engine total connected airflow

$$BPR = \frac{\frac{WA\sqrt{\theta}}{\delta}\left(\frac{\delta}{\sqrt{\theta}}\right) - WA22}{WA22} \qquad (8)$$

<u>Overall Compressor Performance</u>

The overall compressor pressure ratio can be calculated very simply by dividing the measured compressor discharge pressure (appropriately corrected for instrumentation, humidity and specific heat effects) by the engine inlet pressure.

$$OPR = \frac{P3}{P1} \qquad (9)$$

The overall compression system efficiency can be calculated, knowing the overall pressure ratio, engine inlet temperature and compressor discharge temperature (appropriately corrected) through the following equation.

$$\eta_C = \frac{H3I - H1}{H3 - H1} \qquad (10)$$

H1 and H3 can be determined from the appropriate thermodynamic tables as a function of T1 and T3. The ideal compressor discharge enthalpy can be calculated as a function of overall pressure ratio and engine inlet enthalpy.

$$H3I = f(OPR, H1) \qquad (11)$$

<u>Overall Turbine Performance</u>

The overall turbine pressure ratio can be calculated from the measured exhaust gas total pressure (appropriately corrected) and the turbine inlet pressure calculated in equation (2).

$$TPR = \frac{P4}{P5} \qquad (12)$$

The calculation of overall turbine efficiency is somewhat more complicated than the similar calculation for the compressor. First the turbine rotor inlet enthalpy must be calculated from the turbine nozzle cooling flow and the turbine inlet temperature calculated previously.

$$H41 = \frac{(WG4)(H4) + .0318(WA4)(H3)}{WG4 + .0318\ (WA4)} \qquad (13)$$

Next, the untrimmed exhaust gas temperature must be calculated from the measured trimmed exhaust gas temperature (corrected for instrumentation, humidity, and specific heat effects) the T5 ballast resistance, the T5 thermocouple harness resistance and the T5 junction box temperature.

$$T5UT = T5M + \left(\frac{RH}{RES}\right)(T5M - TJB) \qquad (14)$$

The turbine discharge enthalpy can be determined from the calculated temperature and fuel to air ratio using the appropriate thermodynamic

table. The overall turbine efficiency can be calculated using the following equation.

$$\eta_T = \frac{H41 - H5}{H41 - H5I} \qquad (15)$$

The ideal turbine discharge enthalpy used in the above equation can be calculated as a function of overall turbine pressure ratio and turbine rotor inlet enthalpy.

$$H5I = f(TPR, H41) \qquad (16)$$

Engine Pressure Ratio

The engine pressure ratio can easily be calculated from the measured exhaust gas pressure (appropriately corrected) and measured engine inlet pressure.

$$EPR = \frac{P5}{P1} \qquad (17)$$

Engine pressure ratio is a very important parameter because it is directly related to both nozzle pressure ratio and thus thrust and is also generally very close to fan pressure ratio. This parameter is an excellent indicator of engine performance.

APPENDIX B: LUBRICANT/BORESCOPE/CHIP DETECTOR REPORTS

DEPARTMENT OF THE AIR FORCE
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES (AFSC)
AIR FORCE AERO PROPULSION LABORATORY
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO ATTN OF: SFL

18 Nov 77

SUBJECT: Lubricant Monitoring; Tf-41-A1 Engine SN 141677

TO: AFAPL/TBA (Bob May)

1. Analyses and evaluation of lubricant samples taken from above referenced engine during test stand operation are as follows:

a. Sample Identification:

Lab No.	Sample Date	Engine Total Hours	Remarks
OP-98-1	9 Aug 77	0	Drum Sample 0-76-4B
-2	9 Aug 77	0	Engine Sample
-3	22 Aug 77	-	Engine Oil Tank (after leak)
-4	1 Sep 77	49	Engine Sample
-5	7 Sep 77	50	" "
-6	15 Sep 77	79	" "
-7	23 Sep 77	100	" "
-8	28 Sep 77	120	" "
-9	12 Oct 77	150	" "
-10	19 Oct 77	175	" "
-11	20 Oct 77	175	" " (Lab request sample)
-12	20 Oct 77	187	" "

b. Physical Property Data:

Sample	Total Acid Number	Viscosity cs @ 100^{o}F	M1 Foam	Static Foam Test Collapse Time (sec)
OP-98-1	0.07	13.83	75	54
-2	0.01	13.79	-	-
-3	--	--	165	30
-4	0.03	13.84	275	55
-5	0.04	13.94	195	38
-6	0.03	13.95	125	26
-7	0.05	13.86	155	70
-8	0.04	13.91	75	11
-9	0.02	13.98	-	-
-10	0.08	13.95	-	-
-11	--	--	-	-
-12	0.02	13.86	85	29

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

c. Phase Contrast Microscopy Examination for Anti-foam Additive.

OP-98-1	Approximately 10 ppm DC-200 fluid
-2	" " " " "
-3	No DC-200 fluid present
-4	No DC-200 fluid present
-5	- - - -
-6	- - - -
-7	- - - -
-8	- - - -
-9	Trace of DC-200 fluid; less than 2 ppm
-10	" " " " " " "
-11	" " " " " " "
-12	No DC-200 fluid present

d. Wear Metal Analysis:

	Element (ppm)									
Sample	Fe	Ag	Al	Cr	Cu	Mg	Ni	Si	Ti	Mo
OP-98-1	0	0	0	0	0	1	0	3	0	1
-2	0	0	0	0	0	0	0	2	0	1
-3	4	0	0	0	2	0	0	12	0	1
-4	3	0	0	0	2	0	0	6	0	1
-5	1	0	0	0	1	0	0	3	0	1
-6	0	0	0	0	1	0	0	3	0	1
-7	-	-	-	-	-	-	-	-	-	-
-8	-	-	-	-	-	-	-	-	-	-
-9	0	0	0	0	0	0	0	3	0	0
-10	-	-	-	-	-	-	-	-	-	-
-11	1	0	0	0	0	0	0	1	0	1
-12	0	0	0	0	0	0	0	1	0	0

c. Ferrographic Analysis:

OP-98-1 No entry deposit. Few metallic particles and oxide particles down ferrogram.

OP-98-2 Medium entry deposit consisting of "chunk" type particles up to 20 microns in length, several small spheres, oxides. These particles appear to be due to engine build-up. Very few normal wear type particles. Very few particles down ferrogram.

OP-98-3 Light entry deposit consisting of normal wear debris, few oxides and a few carbon appearing particles. Very vew particles down ferrogram.

OP-98-4 Light entry deposit consisting of a few spheres, and normal wear debris and few oxide type particles. Very few particles down ferrogram.

OP-98-5 Light entry deposit consisting of a few oxide and carbon type particles and spalling type wear particles. Very few particles down ferrogram.

OP-98-6 Very light entry deposit consisting of normal debris. Less spalling type particles than previous sample. Very few particles down ferrogram.

OP-98-7 Very light entry deposit. No change from previous sample.
OP-98-8 Very light entry deposit. No change from previous sample.
OP-98-9 Light entry deposit consisting of a few fatigue (chunk) type particles, oxides and carbon. Minor amount of wear debris down ferrogram.
OP-98-10 Dispersed entry deposit consisting of several spheres 5 to 7 microns in dia. and several fatigue chunks. Several "sphere" particles down ferrogram. (Recheck sample requested)
OP-98-11 Light entry deposit consisting of a few chunk type fatigue particles up to 15 microns in size and a few carbon particles. No spheres present. Very few particles down ferrogram.
OP-98-12 Medium entry deposit consisting of chunk type fatigue particles and small normal wear particles. Few bright "plate" type wear particles. Much more normal wear particles down ferrogram. No spheres present.

2. The above physical property test data shows very little lubricant degradation occuring in this engine. This reflects the high oil consumption as reported by engine test stand personnel.

3. Ferrographic analysis shows an increase of wear particles during the last 12 hours of operation. However, due to the amount of wear debris present, high oil consumption and no trend data, the significance of the increase in wear particles is questionable.

4. Spectrometric oil analysis data (SOAP) does not indicate abnormal wear is developing.

H. A. Smith
H. A. SMITH
Lubrication Branch
Fuels and Lubrication Division

DEPARTMENT OF THE AIR FORCE
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES (AFSC)
AIR FORCE AERO PROPULSION LABORATORY
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO ATTN OF: SFL   4 Oct 77

SUBJECT: Analysis of Magnetic Debris on Test Stand TF41 Engine Chip Detector (OP-98)

TO: AFAPL/TBA (Bob May)

1. A chip detector from a TF41 test stand engine retaining a large metallic particle of high interest was submitted to this laboratory for evaluation. The following conclusions were derived from analysis of the particle.

a. The particle as removed from the chip detector had magnetic properties and was about 0.1 x 0.15 x 0.005 in.

b. The particle when viewed from an edge appeared to be composed of two or more layers. The edge view suggested that the particle might be from a plated or coated surface.

c. One of the surfaces was observed to be bright and metallic while the other appeared to be dark. The bright surface was worn with "wear tracks" and gouges. It also appeared to be poured or molded rather than machined. The dark surface was found to be less than 0.0005 inch thick and might be a carbon coating, perhaps from lubricant deterioration.

d. When a section of the particle was heated in air at 600^{o}F for 5 minutes, the bright side was not discolored indicating resistance to oxidation. However, micron sized particles or chips - some loose on and some imbedded in the surface - were blued indicating oxidation. The dark side appeared to darken more on strong heating and similar debris to that found on the bright side was blued. The heating experiment suggests a metallic plating or coating on one side which is resistant to oxidation which has had contact with ferrous alloy. The darker side may be carbon on a metal surface contaminated with ferrous debris. Neither side exhibited the color of a copper/brass alloy.

e. A small section of the particle was dissolved in acid. A test for silver on that solution was negative.

f. Another section of the particle when dissolved and prepared for atomic absorption analysis indicated an abundance of nickel. A check was also made for chromium, aluminum, magnesium, and tin. None was found in high concentrations.

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

2. Based upon the above observations and upon a search of the TF41 section of the SOAP manual for iron/nickel possibilities, the following sources of the particle are suggested:

a. No. 7 bearing oil seal sleeve

b. No. 3 bearing area gears

c. Oil pump shafting and gears

d. External gearbox gears and shafts

3. Due to the size of the particle, not all atomic absorption analysis possibilities could be explored. Therefore, all of the possible sources for the particle have not been eliminated. However, a lubricant sample has been submitted for a complete SOAP analysis and when those data are available, more information on the wear metals present in the TF41 oil system may provide additional clues to the origin of the metallic debris.

4. If additional information is required concerning the above analysis, please contact H. A. Smith or the undersigned at 54667/54668.

P W Centers

P. W. CENTERS
Lubrication Branch
Fuels and Lubrication Division

AD-A062 835 AIR FORCE AERO PROPULSION LAB WRIGHT-PATTERSON AFB OHIO F/G 21/5
ACCELERATED MISSION TEST OF A TF41 WITH AIRCOOLED SECOND STAGE --ETC(U)
NOV 78 R J MAY
UNCLASSIFIED AFAPL-TR-78-87 NL

2 OF 2
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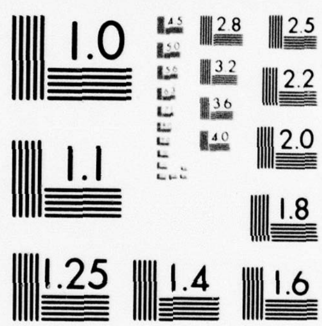


MICROCOPY RESOLUTION TEST CHART

Inter-Organization

Detroit Diesel Allison Division of General Motors Corporation

P. O. Box 894 ▮ Indianapolis, Indiana 46206

DAYTON ZONE OFFICE FILE

SUBJECT

CIRC.	
Walters	
Christman	
M-656	
Bell	
Liedtke	10/10

To G.C. Van Cleve Address

From A.G. Anderson Date October 4, 1977

Subject Hot Section Borescope Inspection, TF41-A-1, S/N 141677 at Wright-Patterson AFB, OH

The writer traveled to Wright-Patterson AFB, Ohio, on Friday, September 30, 1977 to perform a hot section borescope inspection on engine 141677 undergoing AMT testing at that installation. A DDA-owned fiber optic borescope was used for this inspection.

Engine 141677 had logged 118.3 hrs (99.3 AMT) running time at WPAFB to date.

Contact personnel at WPAFB were:

Mr. Richard Krabal - ASD
Mr. R.O. Liedtke - DDA Service, DAZO

Mr. Krabal's group had the engine ready for complete borescope inspection upon the writer's arrival. All fuel nozzles, HPT2 borescope port plug and intermediate case plugs were removed.

Fuel nozzles all exhibited moderate carbon build-up on the fuel spray nozzle aft faces. Fuel spray orifices were clear; however the outer air passages were plugged. No outer air shroud burning or erosion was evident.

HPT1 vanes were in very good condition with no cracks or operating damage noted. Minor hot spots (discoloration) were evident on the L.E. of the center vane of No. 8 segment in No. 5 liner area and No. 14 segment in No. 8 liner area. No erosion or distortion was evident with these hot spots. Several vanes displayed erosion of the surface coating from the LE area aft a short distance which at first viewing appeared as ragged edges and possible crack areas.

HPT1 blades were in good condition with no distress noted.

HPT2 vanes and blades were in good condition. The Olympus fiber optic borescope does not provide the proper view of the HPT2 vanes and blades due to the limiter area to "bend" the tip and still not trap the scope between the blades and vanes.

All combustion liners appeared in good condition with minor burning or erosion of inner edges of air chutes being seen in several liners.

Igniter plugs displayed minor erosion considered normal for the time operated.

Up-the-tailpipe viewing of the LP turbine area disclosed no evidence of distress or damage. LPT2 blades did exhibit a light gray or off-white discoloration or coating.

HPC 11 blades and OGV's were in good condition with no nicks or dents seen.

HPC IGV's and HPC 1 blades were in good condition. Considerable dirt or oil buildup was seen on the HPC 1 blades and vanes, however.

LPC and IPC blades and vanes were also in good condition but dirty for the time operated.

No conditions were noted that would preclude further operation of engine 141677 on the present test program at ASD.

A. G. Anderson
Senior Service Engineer

jw

cc: M. H. Gossett, D. P. Hoose, J.H. Duke, R. Krabal - ASD via DAZO,
R.O. Liedtke - DAZO, 141677

Inter-Organization

Detroit Diesel Allison Division of General Motors Corporation

P. O. Box 894 | Indianapolis, Indiana 46206

CIPC.
Walters
Christman
Bell
Liedtke

DAYTON ZONE OFFICE FILE

OCT 2 6 1977

SUBJECT

To	G.C. Van Cleve	Address	
From	A.G. Anderson	Date	October 20, 1977
Subject	Borescope Inspection, AMT Engine 141677, WPAFB, OH		
Reference	M-650 (Previous Inspection) dated October 4, 1977		

On Thursday, October 13, the writer received a request for DDA assistance to perform a borescope inspection on the subject engine. During AMT running, specialized instrumentation installed on this engine had indicated sudden increase in value over what had been considered normal. Some ASD personnel had interpreted this increase to an internal failure of gas path hardware. ASD/YZS41 requested a borescope inspection be accomplished to verify the engine condition before further action was implemented.

The writer obtained a fiber optic borescope from Tool's Group and vent tube spanner wrench from PH 8 assembly and traveled to WPAFB on Friday, October 14th.

The inspection accomplished consisted of viewing of the HPT1 turbine blades (all) thru No. 9 fuel nozzle port, the HPT1 vanes aft of No. 9 combustion liner, all HPT2 blades thru the HPT2 vane inspection port and the LP turbine area from the rear. No evidence of damage or distress of any kind was noted.

The HPC11 blades and OGV's were viewed from No. 9. Fuel nozzle port the HPC1 blades and IGV's inspected thru the intermediate case viewing ports. Again, no problems were seen. The visible areas of the LP-IP compressor section were also in serviceable condition.

The HPC7 blade/vane area was viewed thru the 7th stage bleed port and conditions were considered excellent.

Test stand personnel commented that oil consumption during cycle testing of engine 141677 was steadily rising and based on previous discussions with ASD and DDA Engineering, the 6866031 metering plug (orifice) was removed from the 6861422 HP turbine bearing vent tube. Subsequent information received indicates the engine oil consumption continues to increase. The LP turbine section of this engine exhibits a heavy even white or light gray coating usually indicative of engine internal oil leakage.

No conditions were evident from the inspection conducted on engine 141677 that indicated any internal problems existed in gas path areas normally accessible to borescope viewing. AMT testing was to continue as scheduled.

A.G. Anderson

A.G. Anderson
Senior Service Engineer

S/N TF41/Misc.

EXPERIMENTAL ASSEMBLY & TEST INSPECTION
TEARDOWN INSPECTION REPORT

UNIT 141677 T.D. 1 MODEL TF41 T.D. DATE 2 February 1978

INSPECTORS Fisher/Nicely/Seidel TOTAL TIME ENDURANCE TIME
dl

REASON FOR T.D. Work Request B0128 - Completed 160 Hours AMT Test

PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
Wheel-HPT Stg 2 P/N EX124584, S/N FX15788	Zyglo OK.
Wheel-HPT Stg 1 Wheel Asm P/N 6887237 S/N 10121	Zyglo with shaft, seal and sleeve attached OK.
Blade-HPT Stg 1 P/N 6869795B - 100 pieces	Several blades show light to heavy erosion areas on leading edge. Per Zyglo, 91 pieces OK; 9 pieces have indications as charted on page 2.
Blade-HPT Stg 2 P/N 6892984 - 94 pieces	Per Zyglo 94 pieces have indications as charted on pages 3 through 6.
Vane-HPT Stg 2 P/N 6892950 - 21 pieces	See charts on pages 7 through 12 for Zyglo results.
Vane-HPT Stg 2 (Borescope) P/N EX123--- , S/N XA16141	See chart on page 12 for Zyglo results.
Vane-HPT Stg 1 P/N 6894686 - 20 pieces	See charts on pages 13 through 32 for results of Zyglo inspection.

This completes the report. Any additional information will be submitted as an addendum.

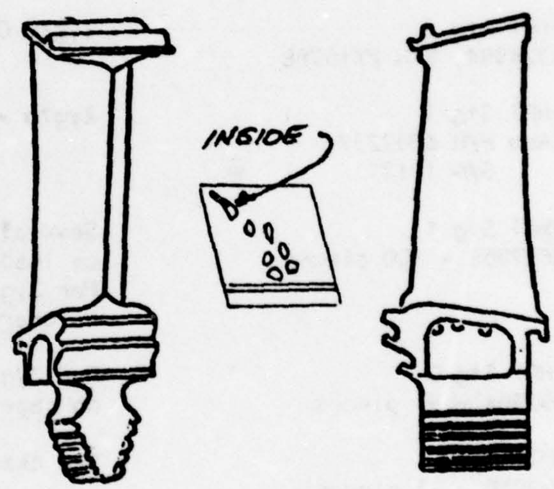
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 - H.P. TURBINE - 1st STAGE BLADE   Ref: 6861247

Unit 141677 T.O. 1 Inspector: [illegible] — Date 1-16-78

Blade P/N 6869735 has indications as shown.

Position	S/N
	L8951801
	L89E0601
	L89H0136
	L88X0908
	L8862189
	L87W 1115
	L89J 0879
	L87X0804
	L87J5409



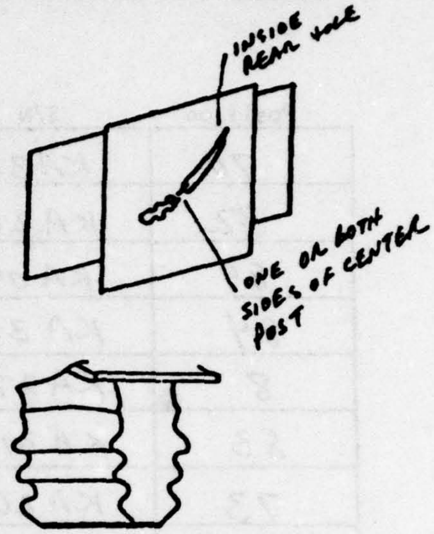
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 - Blade Asm, Rotor HPT Stg 2 Ref: 6892983

Unit 141677 T.D. — Inspector NEELY/FISHER Date 1-20-78

Position	S/N
31	KA083
69	KA179
72	KA360
36	KA091
34	KA034
52	KA080
71	KA211
81	KA423
15	KA336
54	KA214
30	KA120
6	KA411
87	KA093
88	KA287
14	KA189
42	KA038
66	KA219
77	KA247
92	KA021
93	KA434
61	KA162
27	KA036
63	KA032
17	KA094

62 - KA281
60 - KA311



P/N 6892984

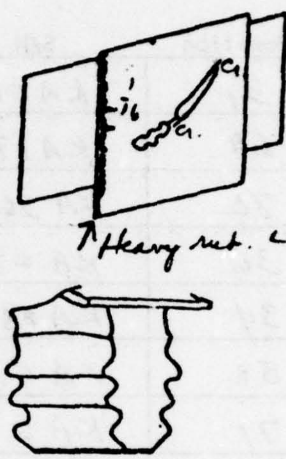
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

S/N TF41/Misc.
Page 4 of 32

TF41 - Blade Asm, Rotor HPT Stg 2 Ref: 6892983

Unit 141677 T.D. 1 Inspector C.N. - [illegible] Date 1-20-78

Position	S/N
70	KA321
32	KA286
89	KA097
84	KA352
8	KA278
83	KA310
73	KA265
37	KA008
74	KA354
98	KA420?
35	KA267
33	KA295
4	KA366
85	KA313
13	KA295
3	KA014
53	KA182
55	KA229
8	KA433?
9	KA089
49	KA161
82	KA208
89	KA405
12	KA368?



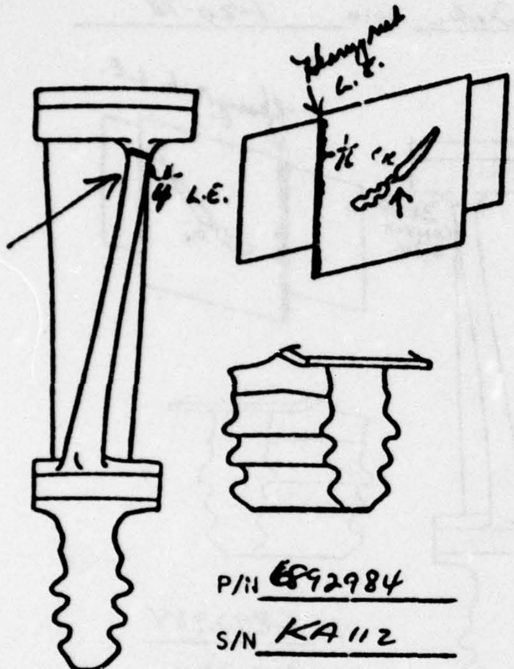
P/N 6892984

11 - KA416 1 - KA187 20 - KA345
50 - KA257 64 - KA184 58 - KA349
7 - KA088 44 - KA270 23 - KA075
65 - KA191 80 - KA315 21 - KA011
40 - KA339 29 - KA183 79 - KA338
41 - KA344 76 KA288 67 - KA087
2 - KA168? 19 - KA154 59 - KA410?
38 - KA383 90 - KA058 56 - KA177
43 - KA264 16 - KA0013 26 - KA334
22 - KA238 18 - KA318 78 - KA129
24 - KA251 91 - KA019
75 - KA081 94 - KA156
39 - KA294 45 - KA043
25 - KA197 57 - KA369?

EXPIRIMENTAL ASSEMBLY & TEST INSPECTION

TF41 - Blade Asm, Rotor HPT Stg 2 Ref: 6892983

Unit 141677 T.D. — Inspector [signature] Date 1-20-78



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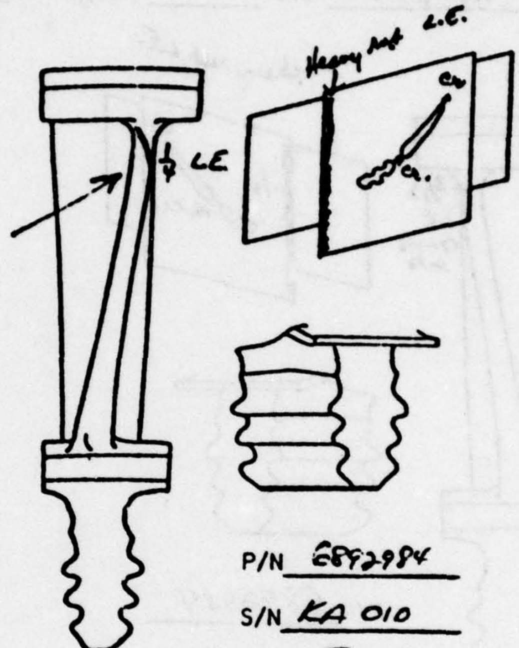
S/N KA112
Pos. 48



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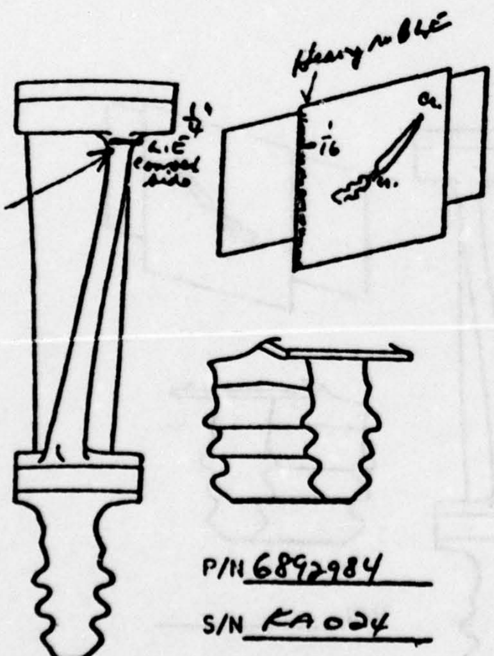
Pos. 51



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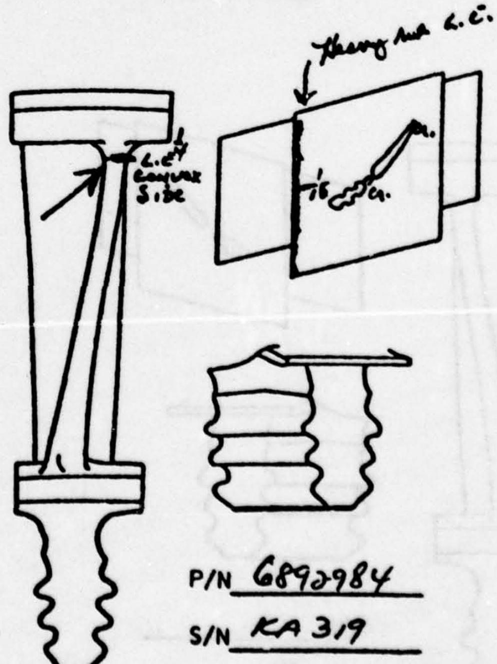
S/N KA024
Pos. 46

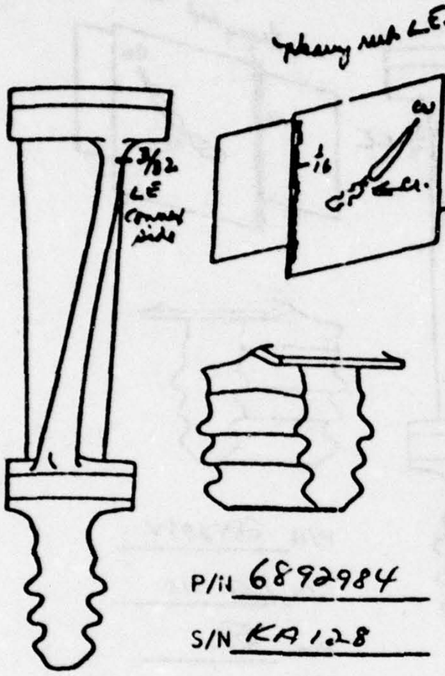


P/N 6892984
S/N KA319
Pos. 5

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 - Blade Asm, Rotor HPT Stg 2 Ref: 6892983

Unit 141677 T.D. – Inspector Neely-Fisher Date 1-20-78



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S/N KA128
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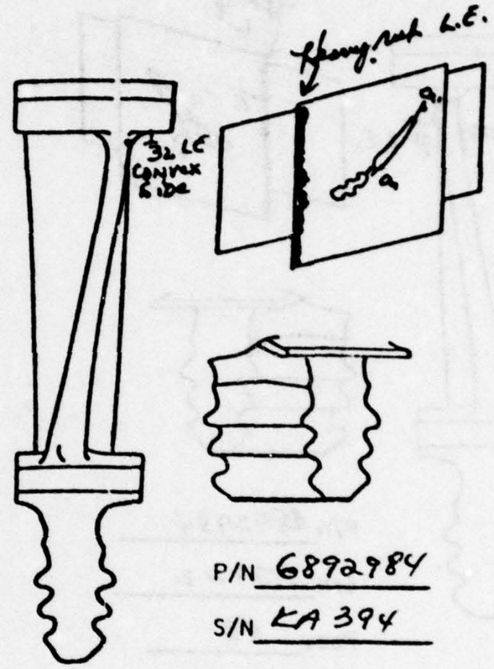

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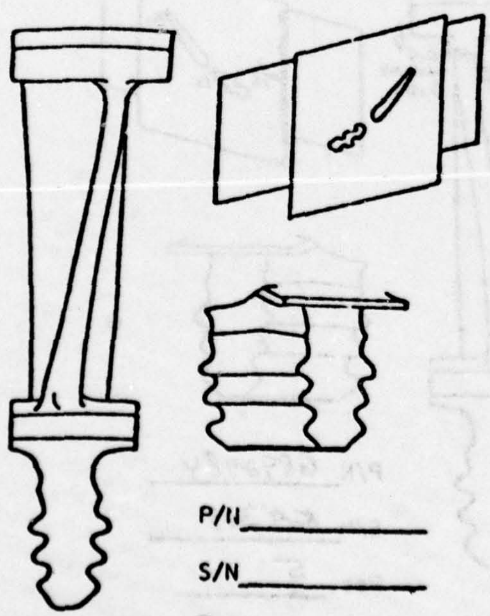
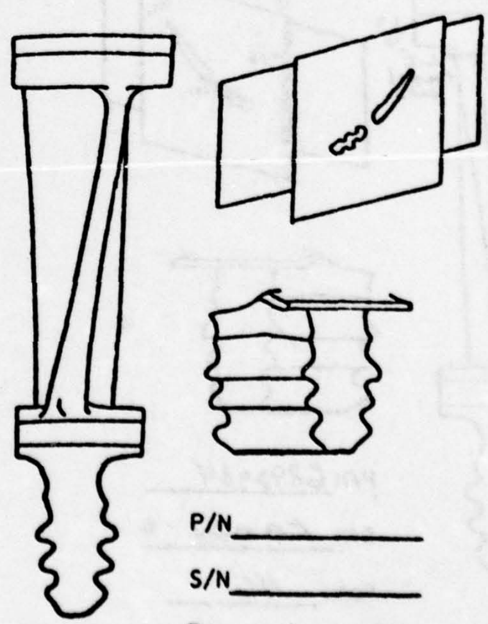
S/N KA394
Pos. 10



P/N
S/N
Pos.



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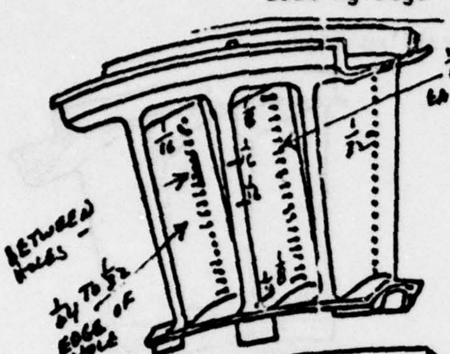
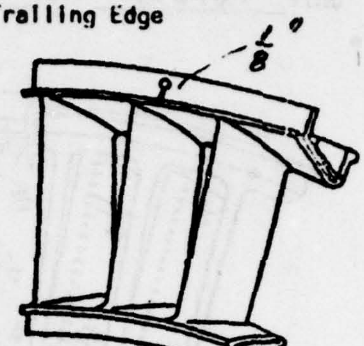
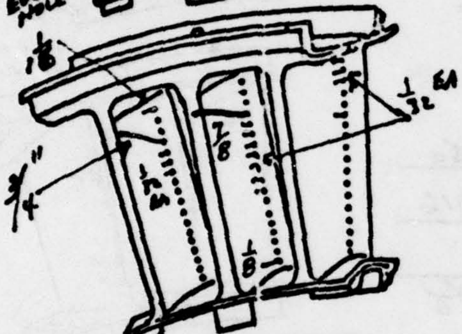
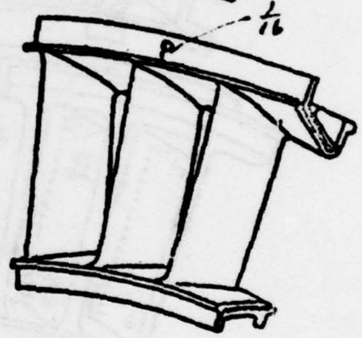
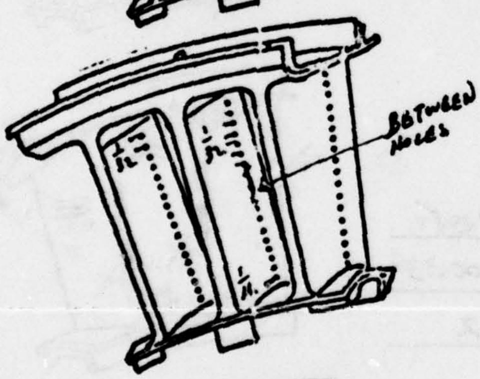
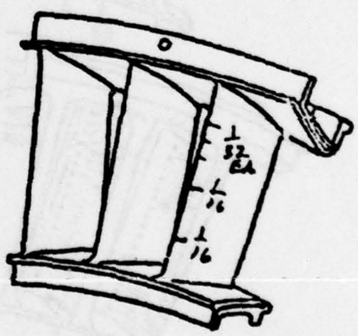
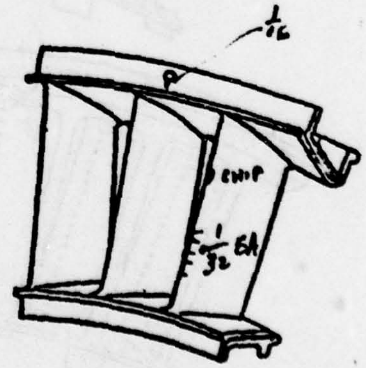
EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY   Ref:

Unit 141677 T.D. 1 Inspector W Fischer Date 1-31-78

WORK REQUEST B0128

No P/N ON THESE PIECES. 6892950 FOUND ON POS 13

Leading Edge		Trailing Edge
	P/N 6X42450 S/N C00031 Pos. 2 DEV ONLY	
	P/N 6892950 S/N C00026 Pos. 14 DEV ONLY	
	P/N 6892950 S/N C00011 Pos. 8 DEV ONLY	
	P/N 6892950 S/N C00048 Pos. 5 DEV ONLY	

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 - HP TURBINE - 2nd STAGE VANE ASSY

Unit 14/1677 T.D. 1 Inspector [illegible] Date 1-31-78

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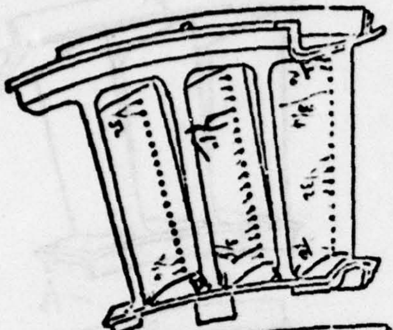
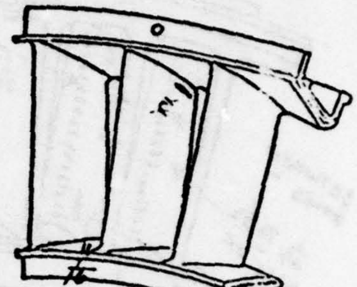
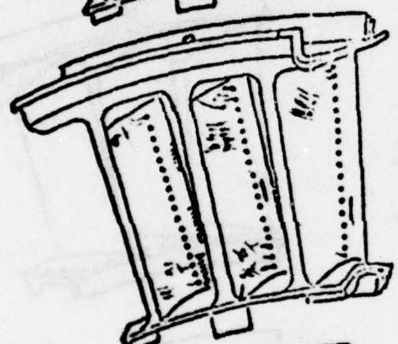


P/N 6892950
S/N C00014
Pos. 22
Dev only





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S/N C00016
Pos. 20
Dev only

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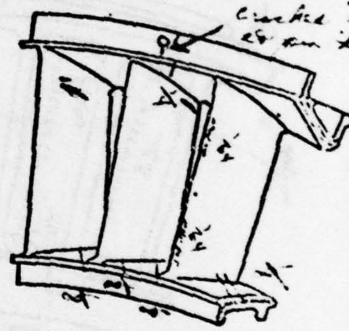

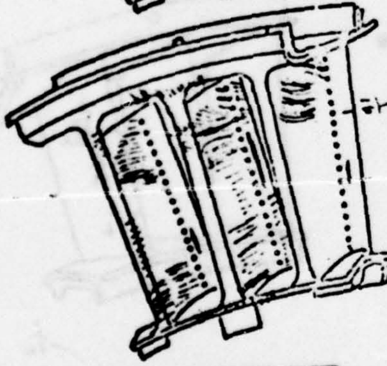

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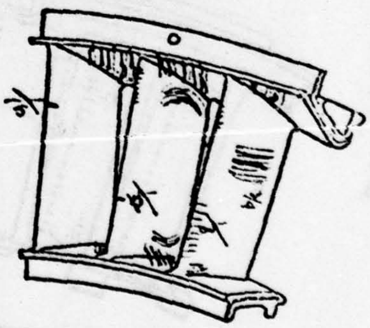
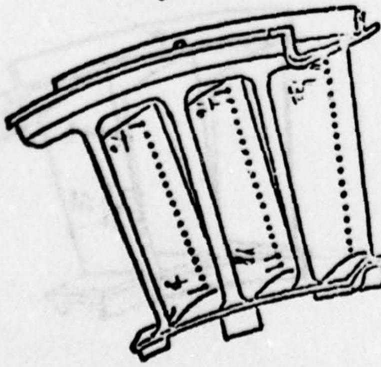
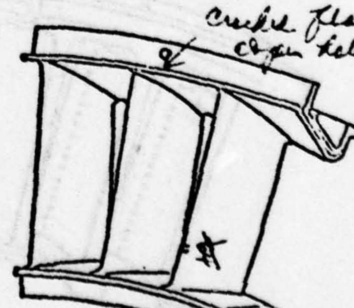




P/N 6892950
S/N C00070
Pos.

Cracked flange at pin hole.

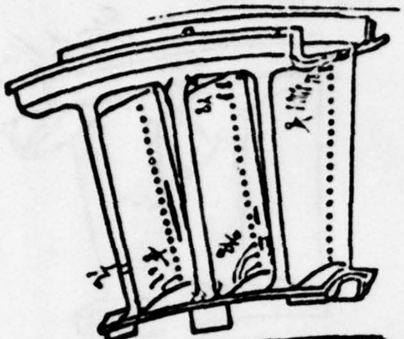


EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

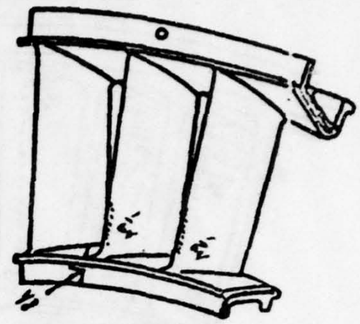
TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY   Ref:

Unit 41677 T.D. 1 Inspector Nuckly Date 1-31-78

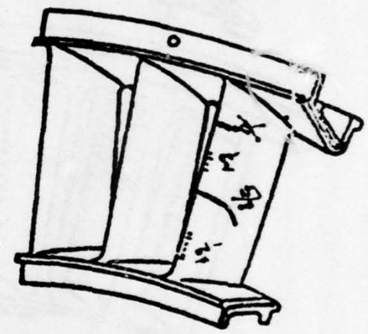
Leading Edge   Trailing Edge

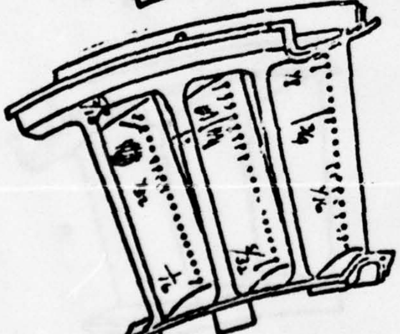


P/N 6892950
S/N C00022
Pos. 11
Dev only

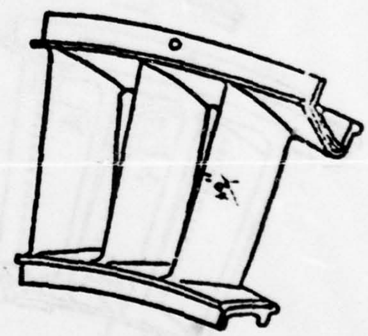


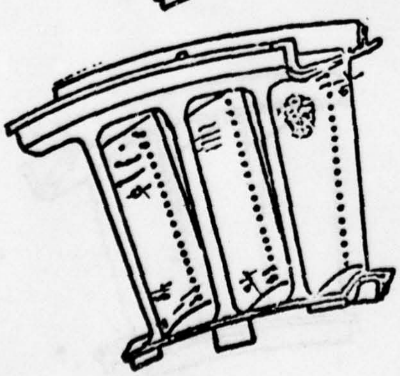
P/N 6892950
S/N C00012
Pos. 6
Dev only





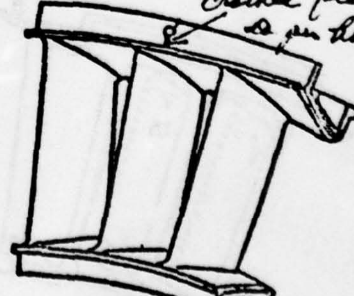
P/N 6892950
S/N C00032
Pos. 3
Dev only





P/N 6892950
S/N C00018
Pos. 17
Dev only

cracked flange at pin hole

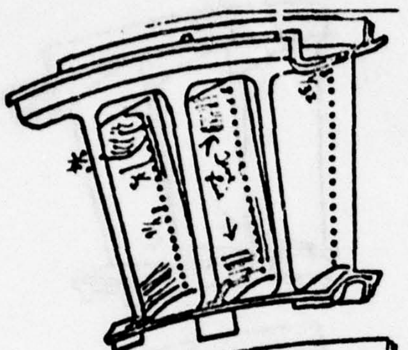


EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

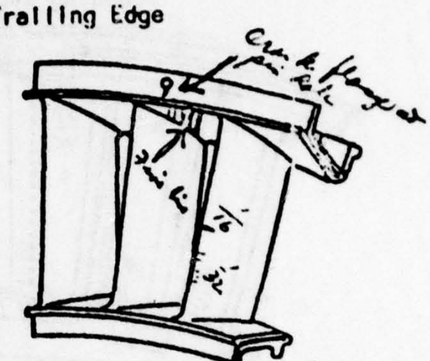
TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY Ref:

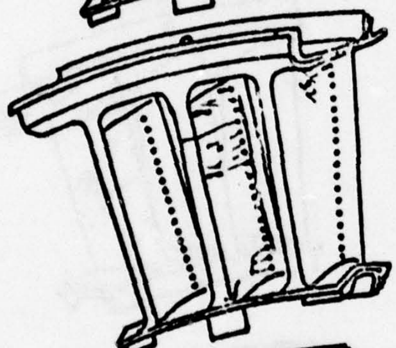
Unit 14/677 T.D. 1 Inspector Kelly Date 1-31-78

Leading Edge | Trailing Edge

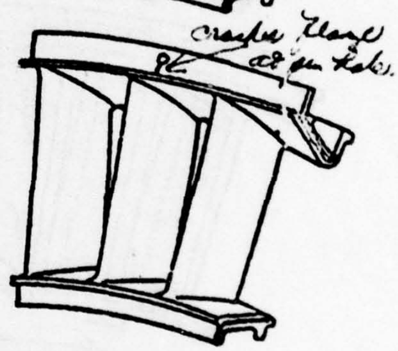


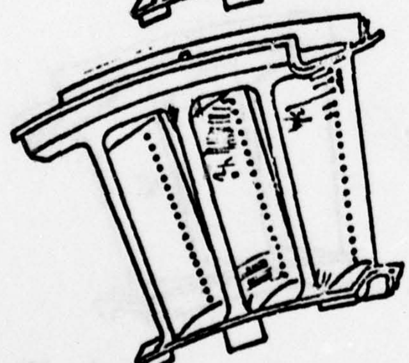
P/N 689295o
S/N C00031
Pos. 16



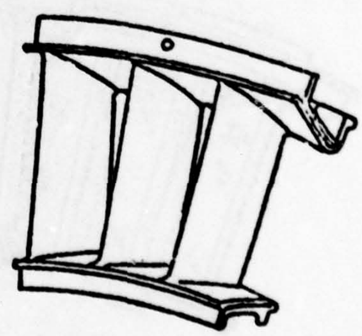


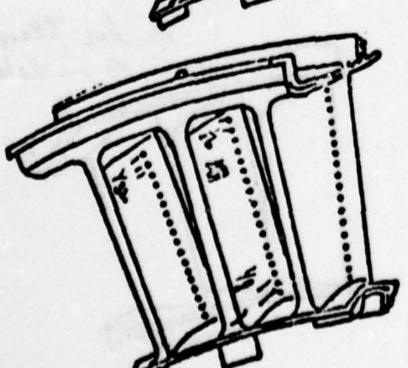
P/N 689295o
S/N C00010
Pos. 9
Den only



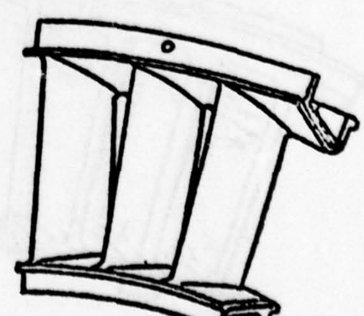


P/N 689295o
S/N C. 00017
Pos. 21





P/N 6892950
S/N C00023
Pos. 4
Den only

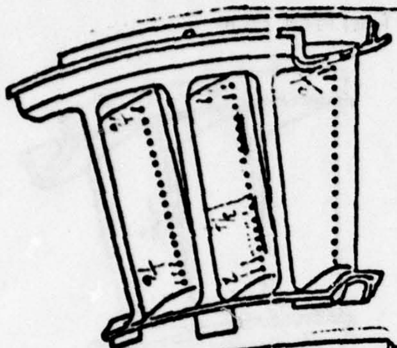


EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

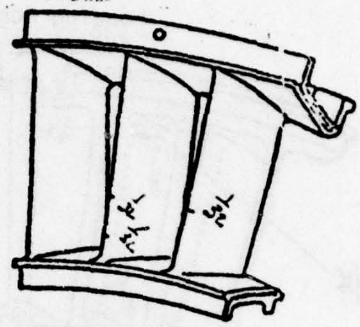
TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY Ref:

Unit 14677 T.D. 1 Inspector Neely Date 1-31-78

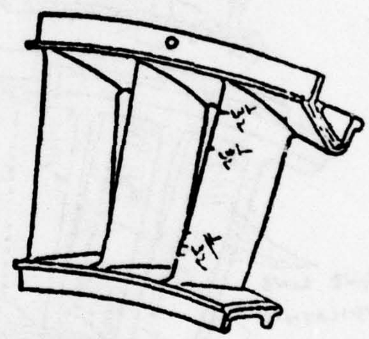
Leading Edge Trailing Edge

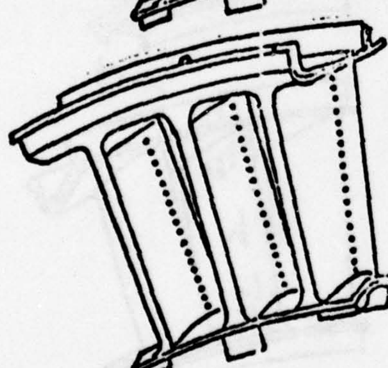


P/N 6892950
S/N C00035
Pos.

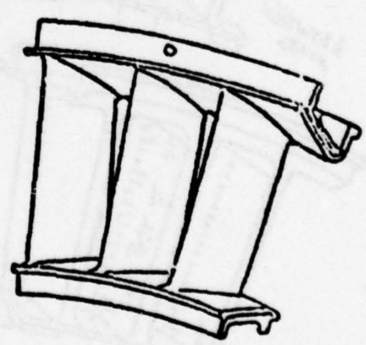


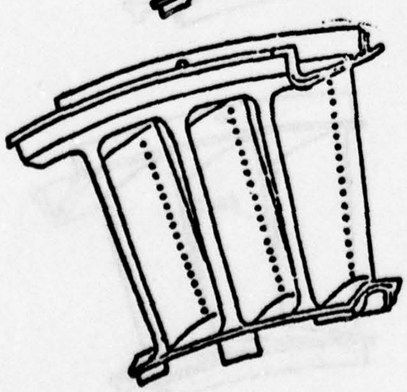
P/N 6892950
S/N C00021
Pos. 19
Dev only.



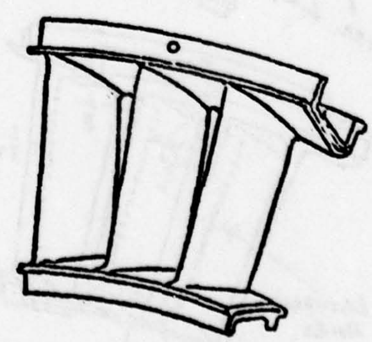


P/N
S/N
Pos.





P/N
S/N
Pos.



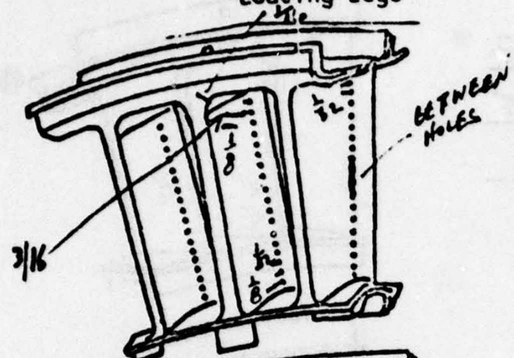
EXPERIMENTAL ASSEMBLY AND TEST INSPECTION

TF41 - H.P. TURBINE - 2nd STAGE VANE ASSY Ref:

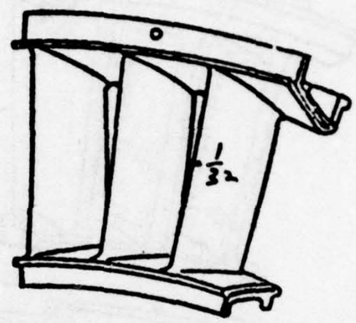
Unit 141677 T.D. 1 Inspector R. Fisher Date 1-31-78

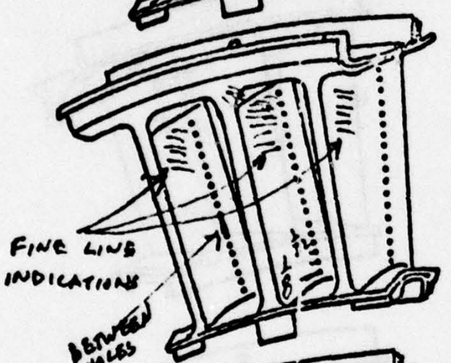
Leading Edge

Trailing Edge

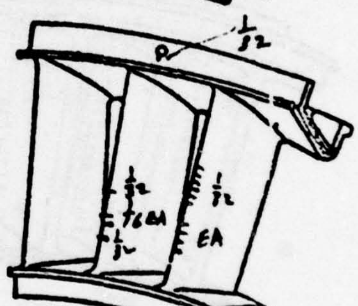


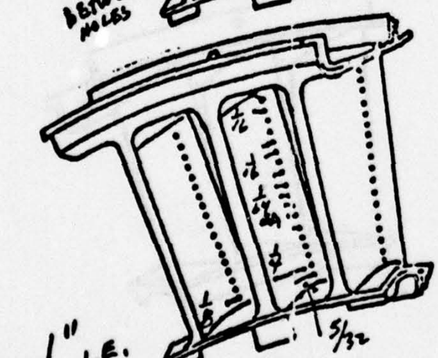
P/N 6892950
S/N C00027
Pos. 1
DEV ONLY



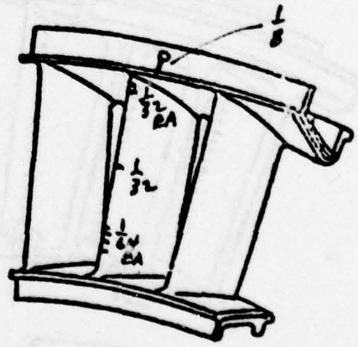


P/N 6892950
S/N C00025
Pos. 15
DEV ONLY

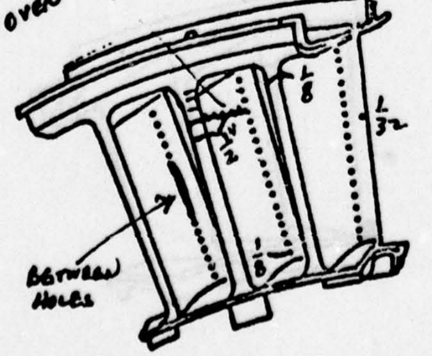




P/N 6892950
S/N C00024
Pos. 13
DEV ONLY



1" OVER L.E.



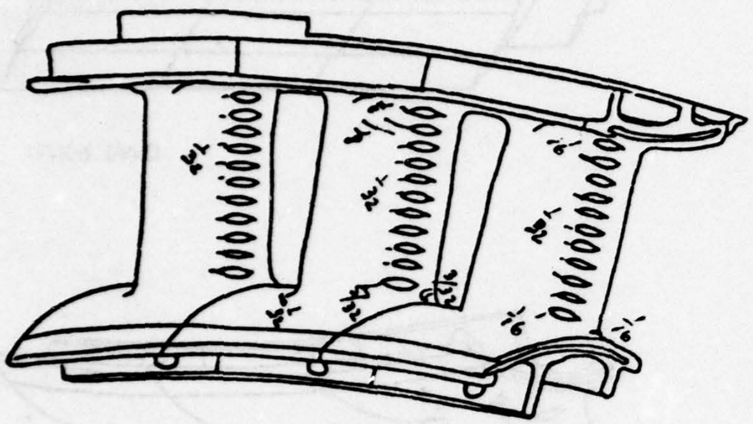
P/N EX123- -
S/N XA16141
Pos. BORE SCOPE POSITION
DEV ONLY

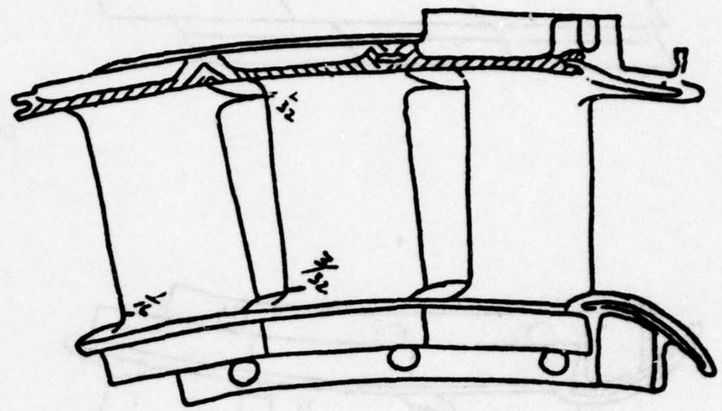
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

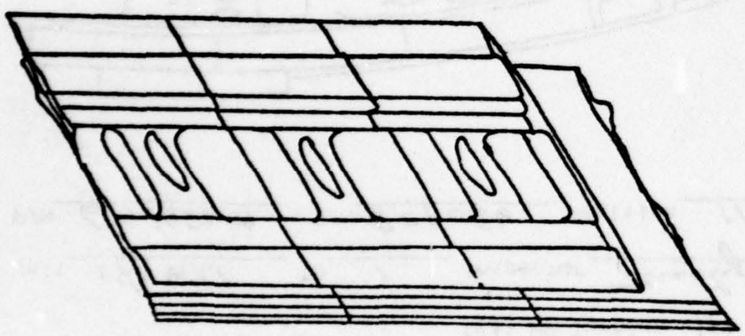
Unit 141677 TD 1 Inspector Mealy Date 2-1-78

P/N 6894686 A S/N @00367 Position 17 Ref: 6862973

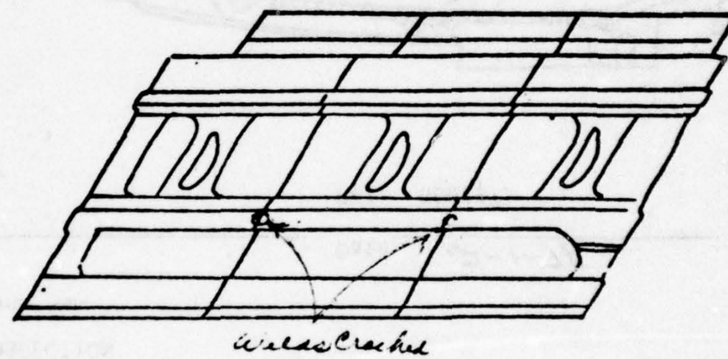




INNER BAND



OUTER BAND

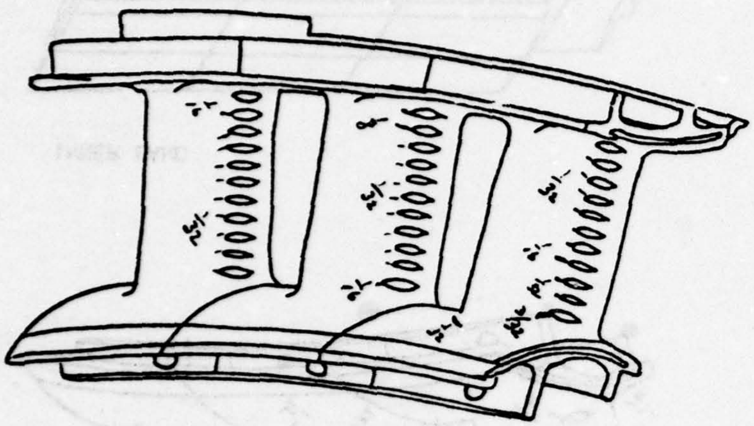


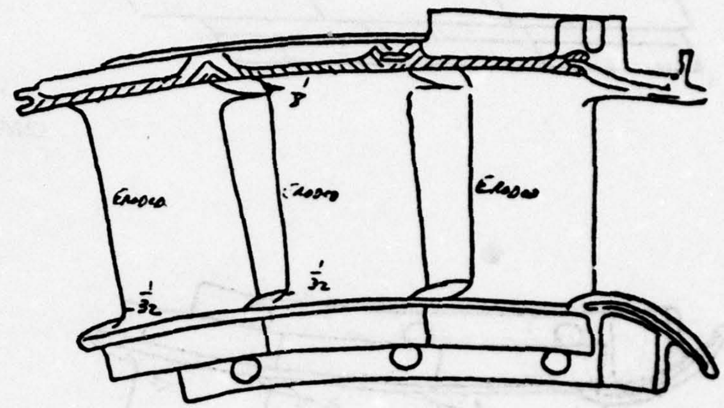
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

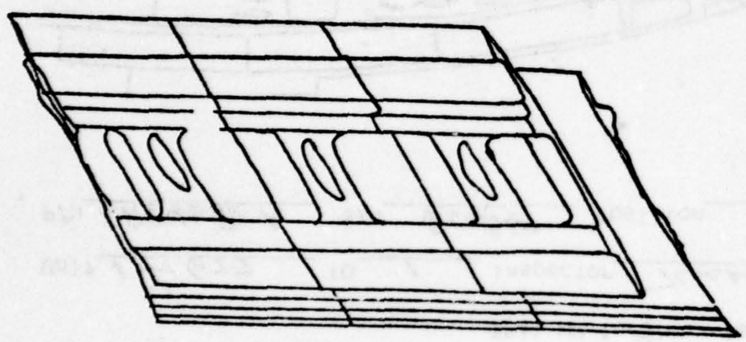
Unit 141677 TD 1 Inspector Mccoly Date 2-1-78

P/N 6894686-A S/N C01056 Position 11 Ref: 6862973





INNER BAND



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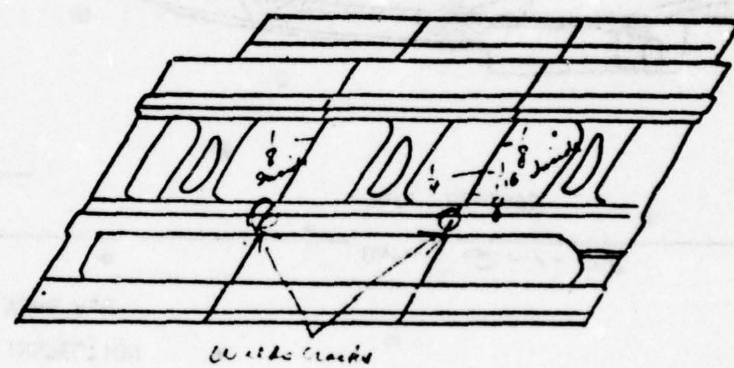
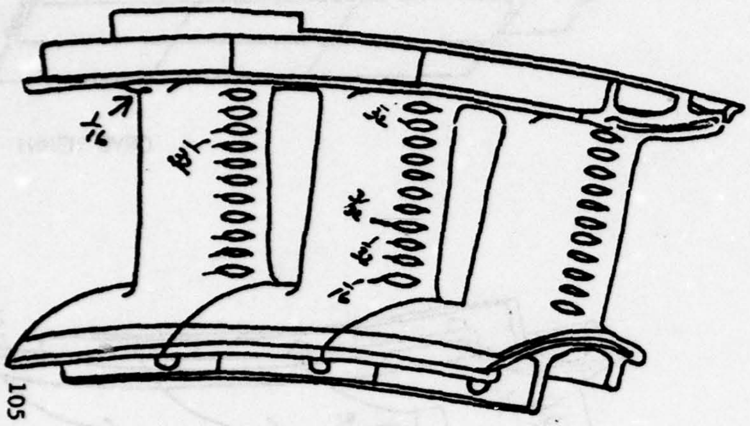


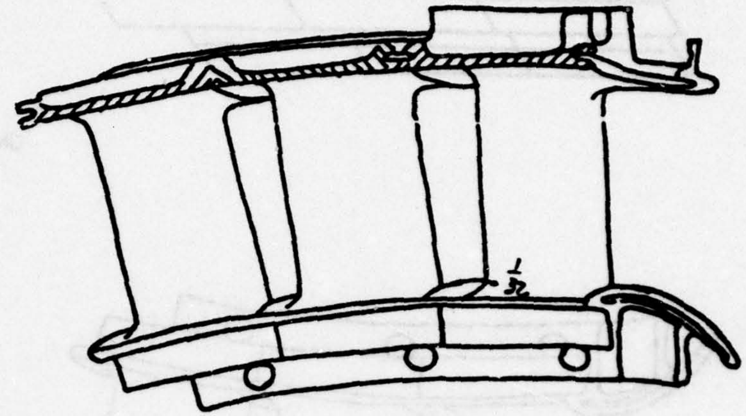
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

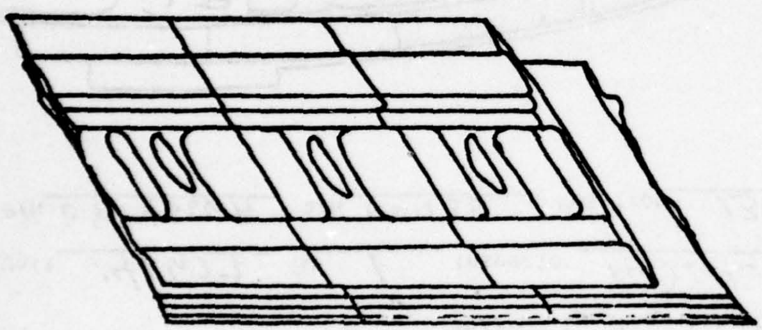
Unit 141677 TD 1 Inspector Ruely Date 2-1-78

P/N 6894486-A S/N Coc842 Position 8 Ref: 6862973





INNER BAND



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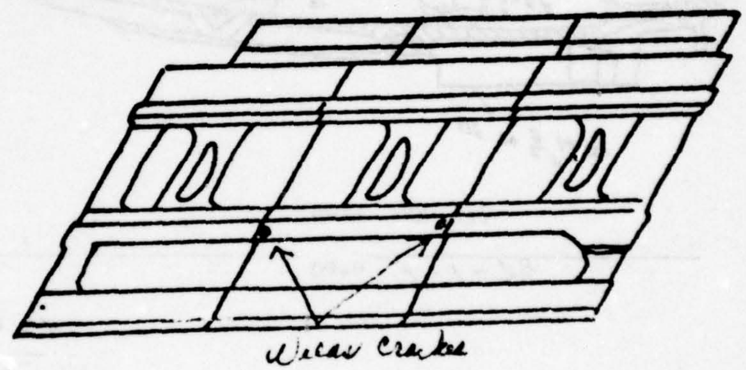
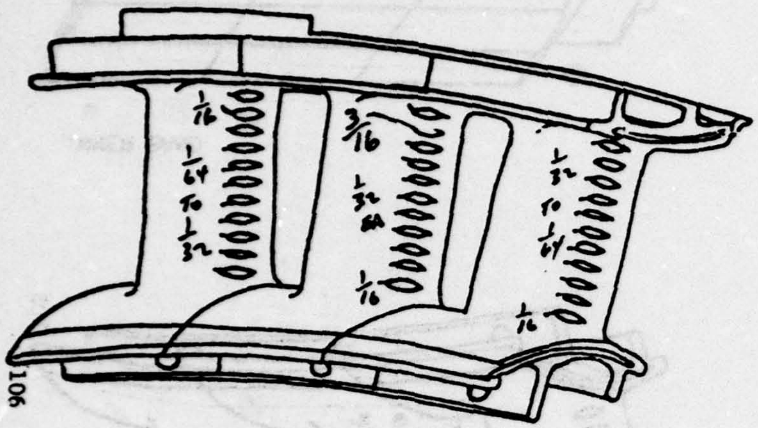


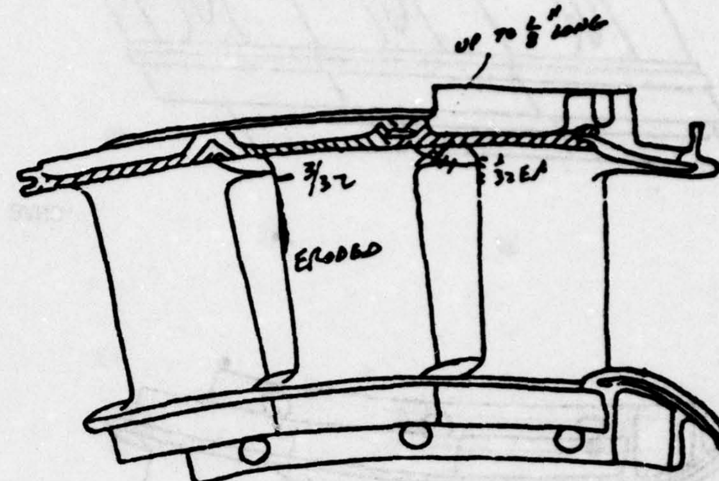
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

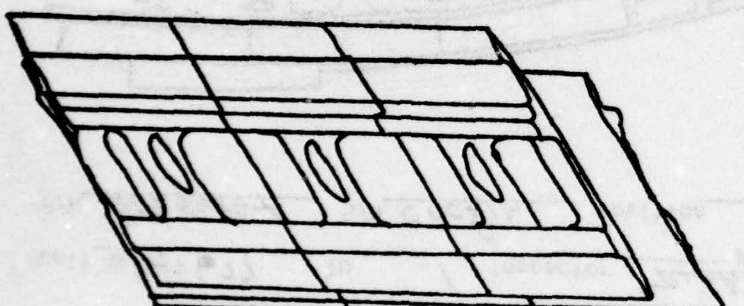
Unit 141677 TD 1 Inspector R. Fisher Date 2-1-78

P/N 6894686A S/N C01135 Position 13 Ref: 6862973

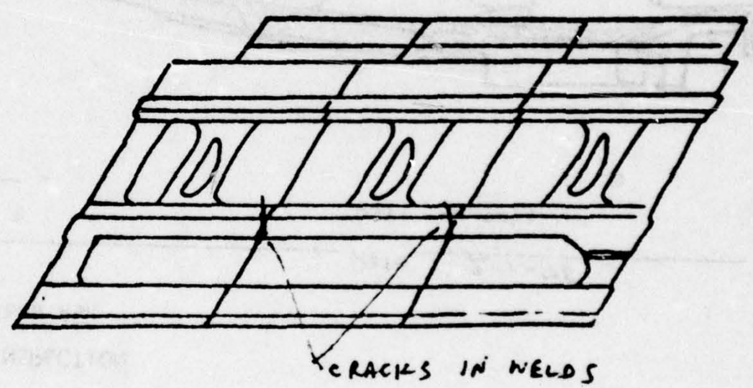




INNER BAND



OUTER BAND

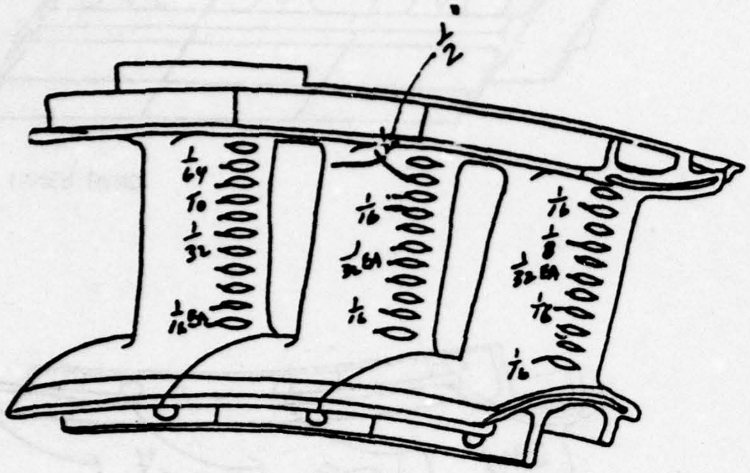


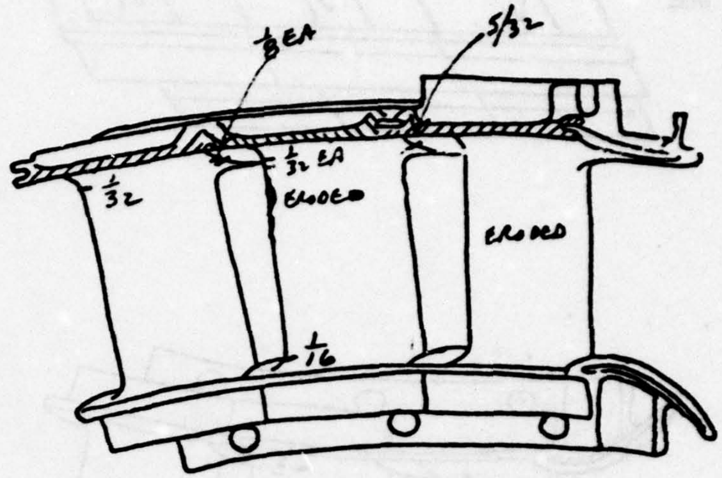
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

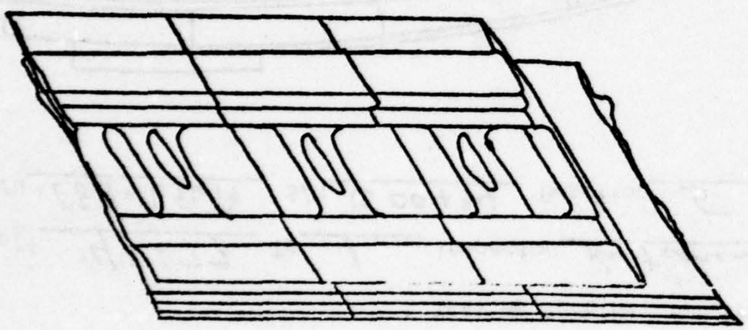
Unit '41677 TD 1 Inspector RW Fisher Date 2-1-78

P/N 6894686A S/N C00605 Position 15 Ref: 6862973

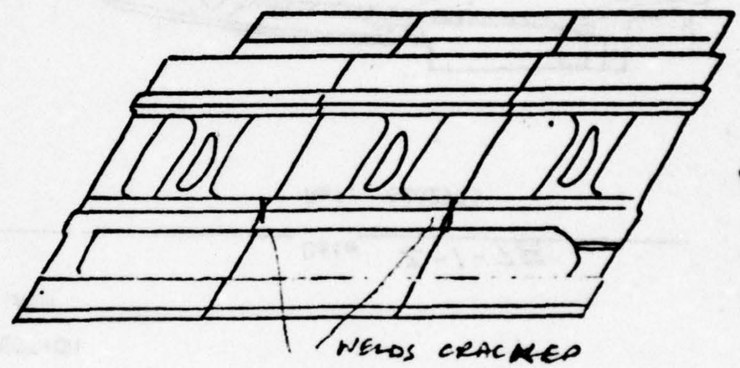




INNER BAND



OUTER BAND

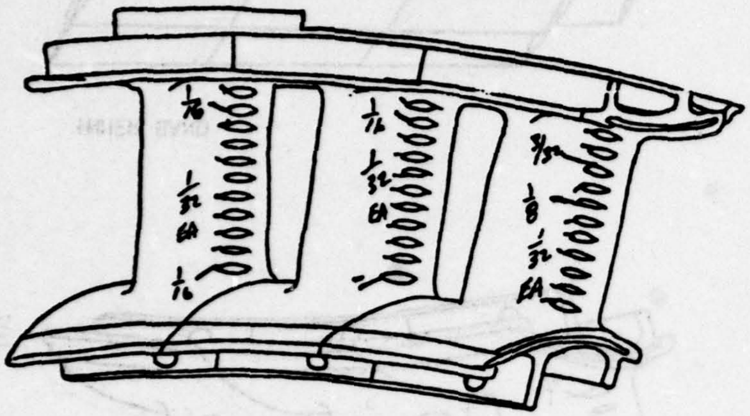


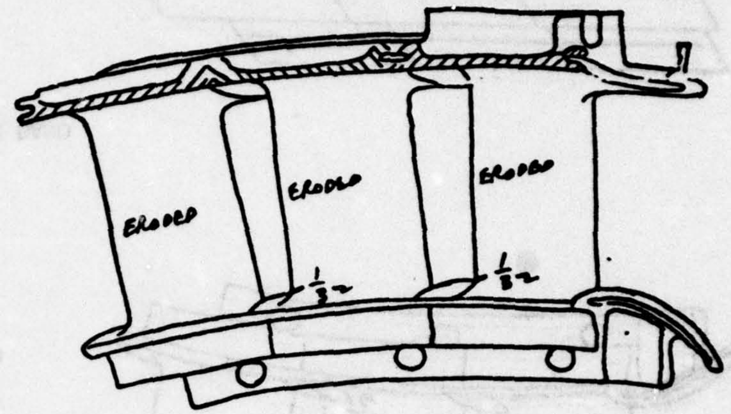
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

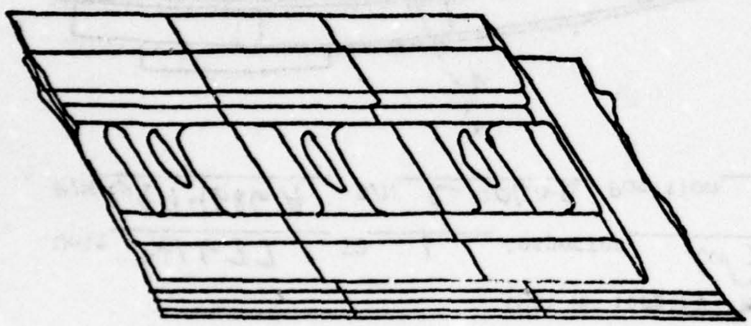
Unit 141677 TD 1 Inspector R W Fisher Date 2-1-78

P/N 6894686A S/N C C0434 Position 5 Ref: 6862973

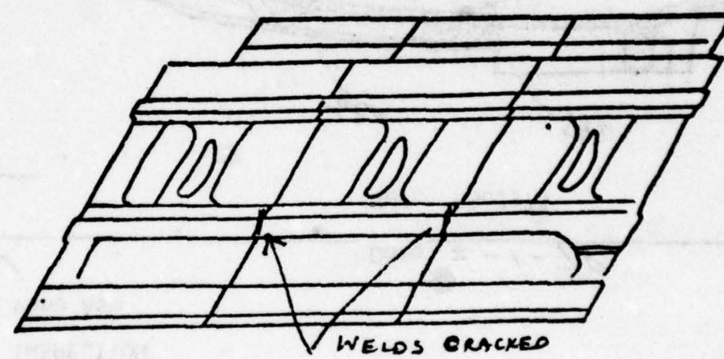




INNER BAND



OUTER BAND



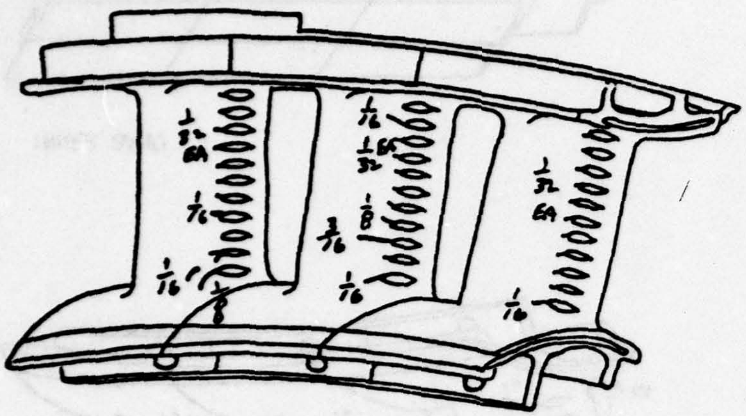
S/N TF41/Misc.
Page 18 of 32

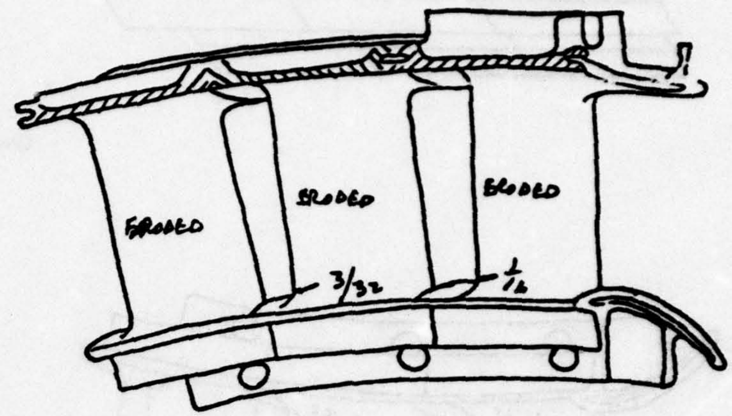
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

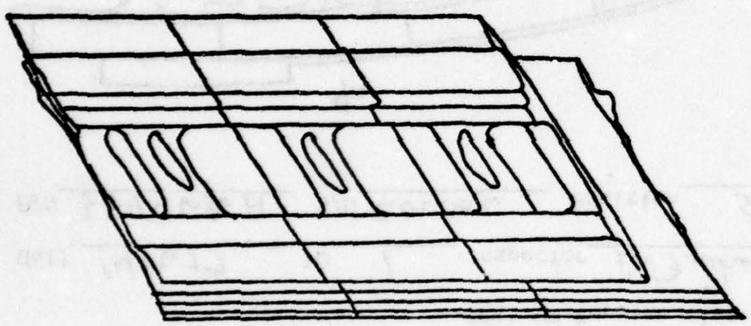
Unit 141677 TD 1 Inspector Rw Fisher Date 2-1-78

P/N 6894686 A S/N C 00619 Position 20 Ref: 6862973

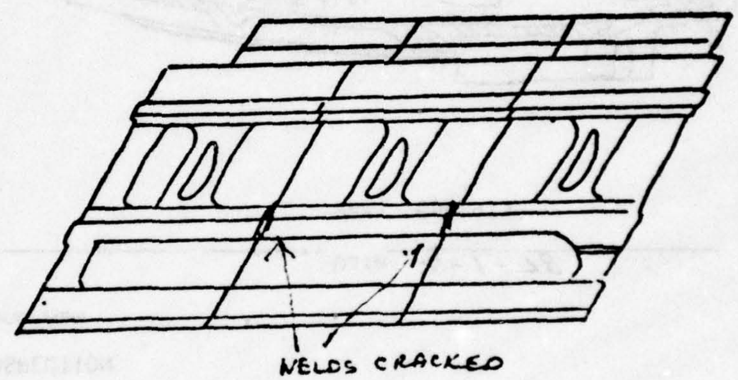




INNER BAND



OUTER BAND

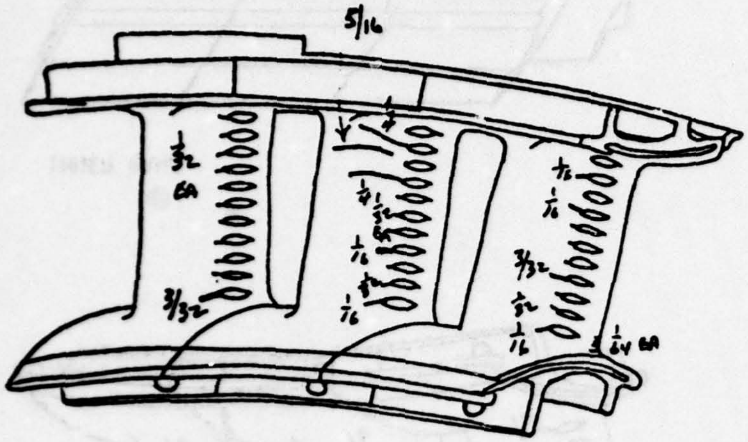


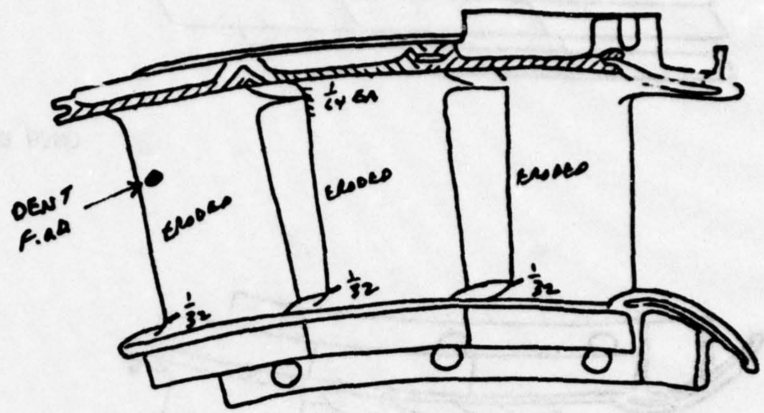
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 141677 TD 1 Inspector [illegible] Date 2-1-78

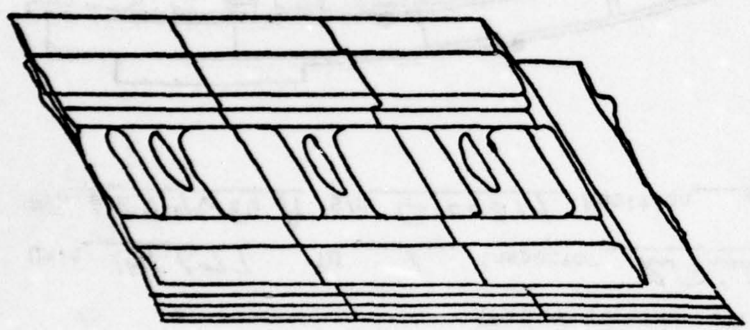
P/N 6894686A S/N C00006 Position SIX Ref: 6862973

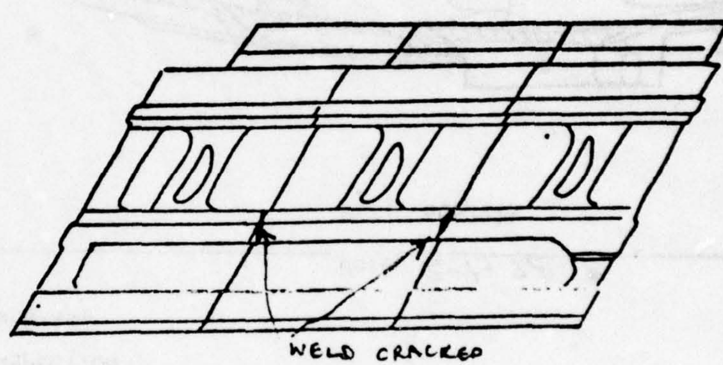




INNER BAND

OUTER BAND



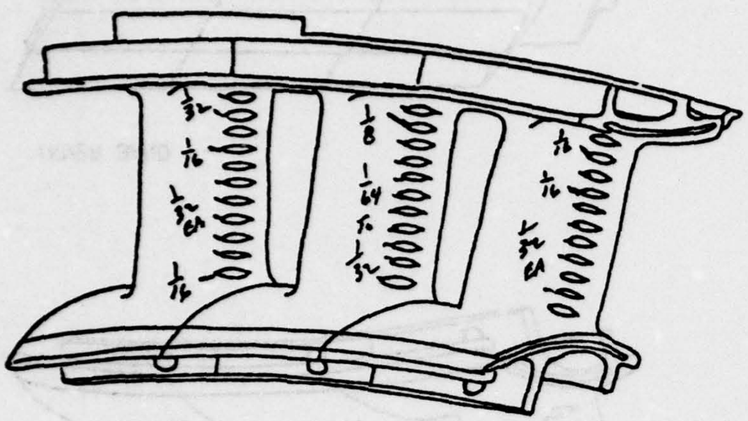


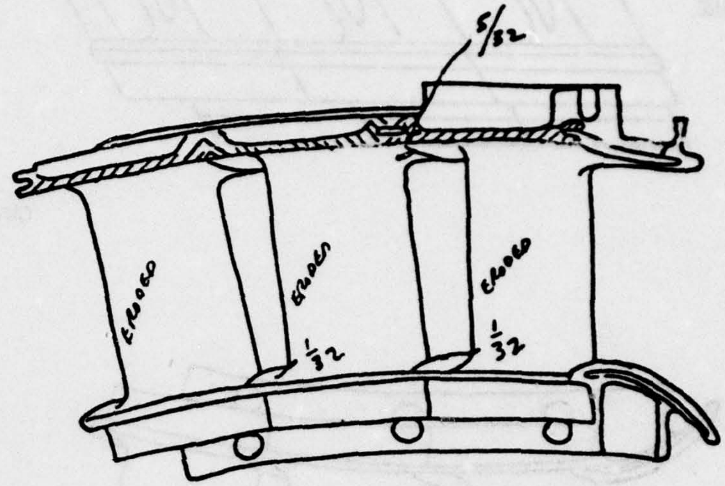
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 141 677 TD 1 Inspector Rw Fisher Date 2-1-78

P/N 6894686A S/N C00502 Position 10 Ref: 6862973





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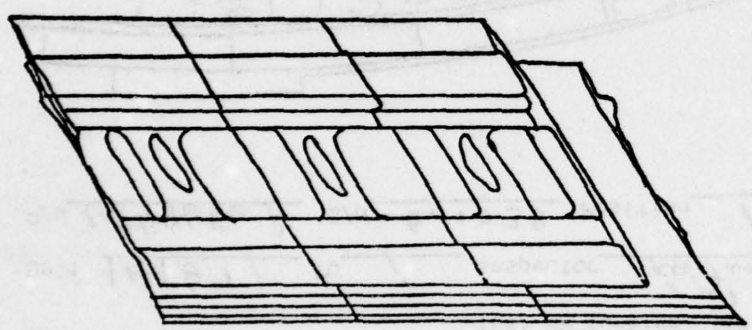

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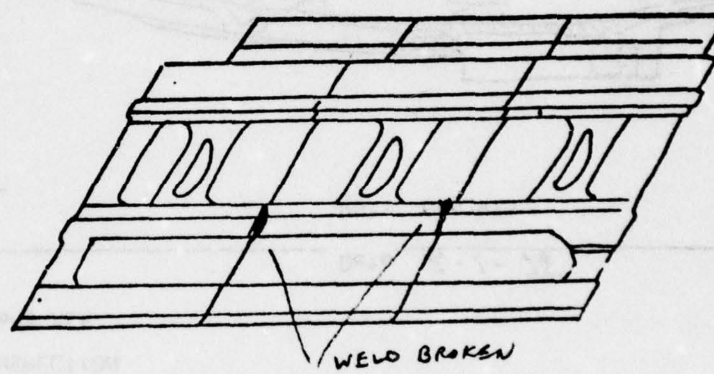
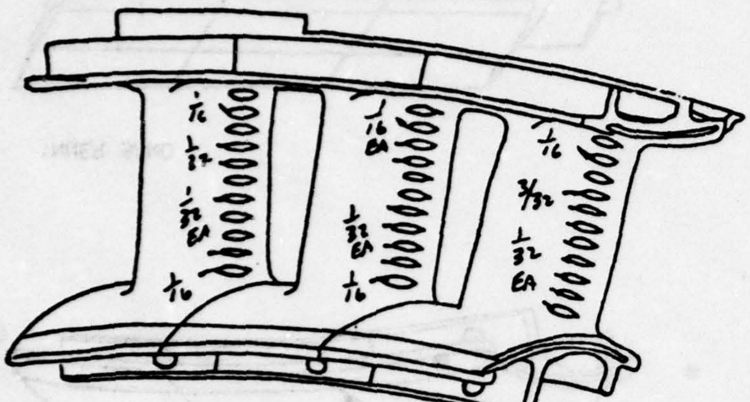


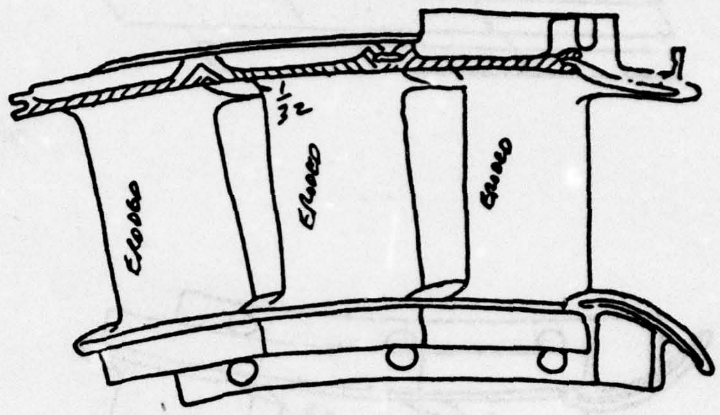
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 141677 TD 1 Inspector R. Fisher Date 2-1-78

P/N 6894686 A S/N C01038 Position 18 Ref: 6862973





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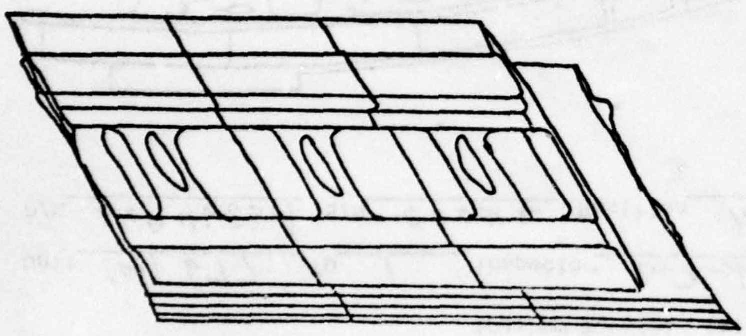

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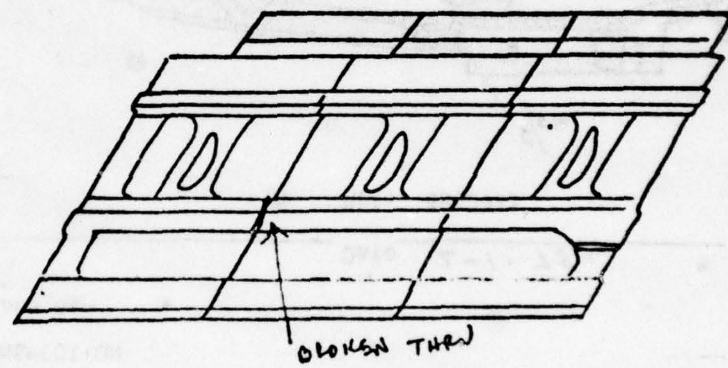
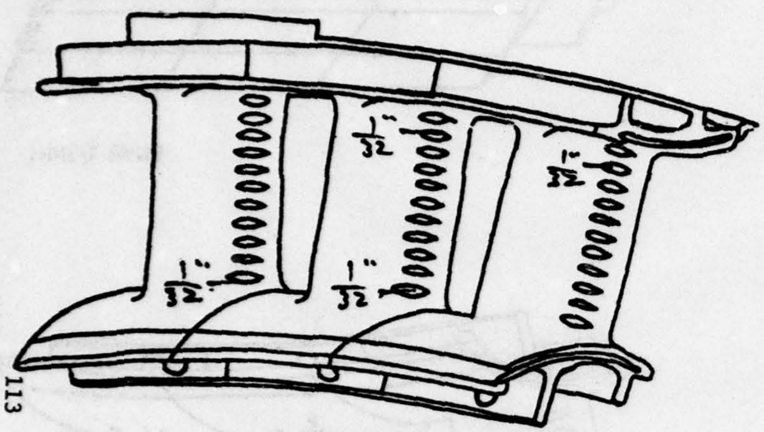


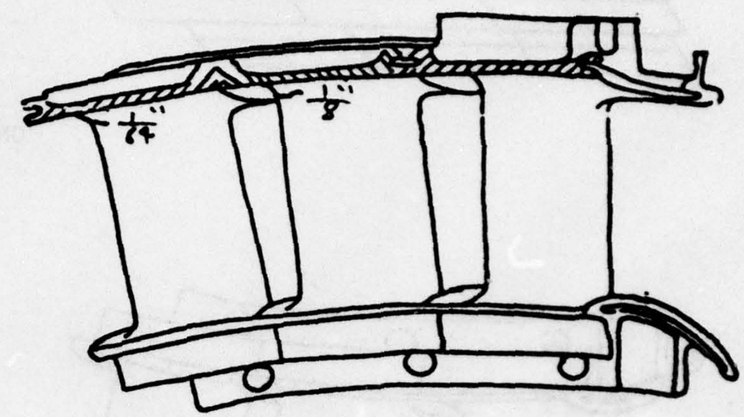
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 141677 TU 1 inspector [illegible] Date 1-31-76

P/N 6894686-A S/N C01087 Position 7 Ref: 6862973





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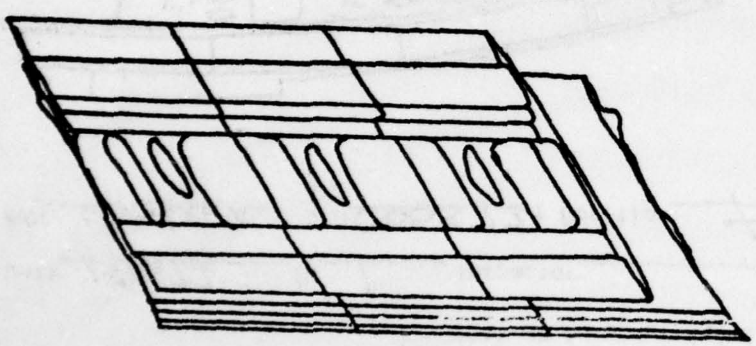

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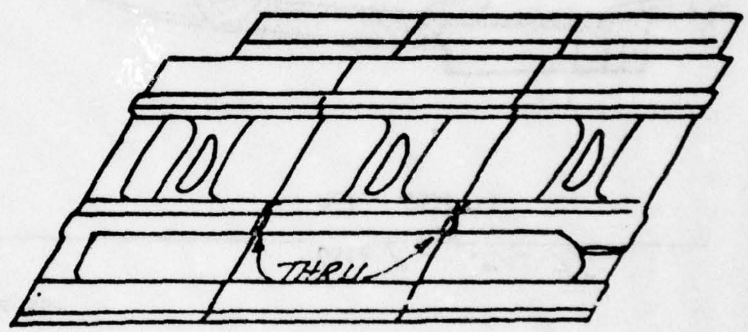

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 141677 TU 1 Inspector ______ Date 1-31-78

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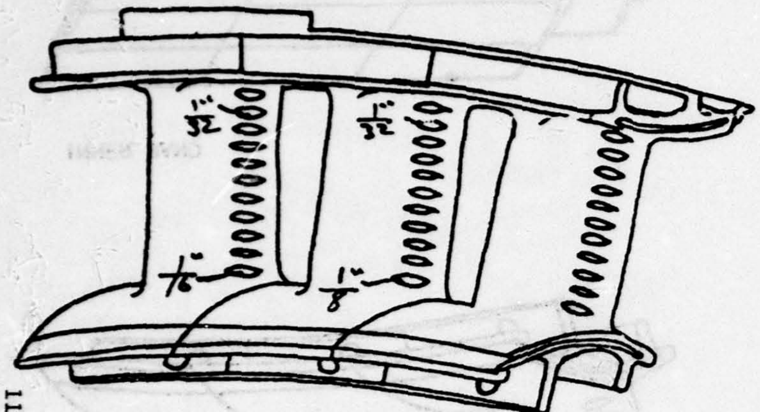

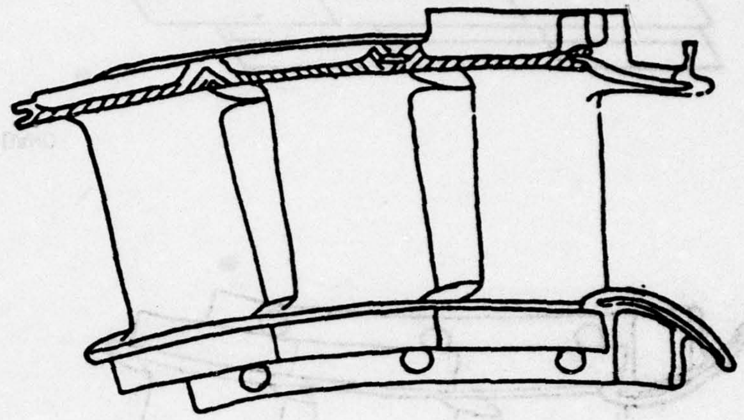

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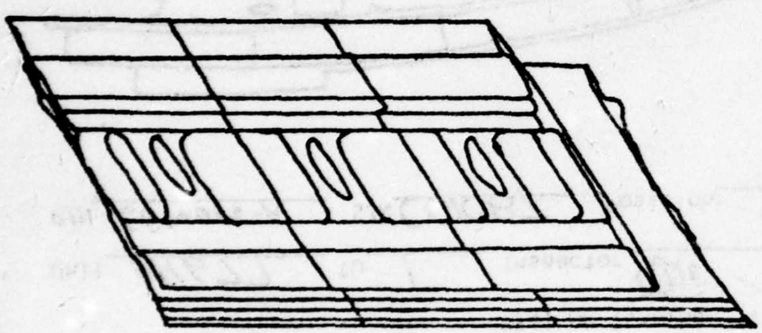

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EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 141677 TU 1 Inspector [illegible] Date 1-31-78

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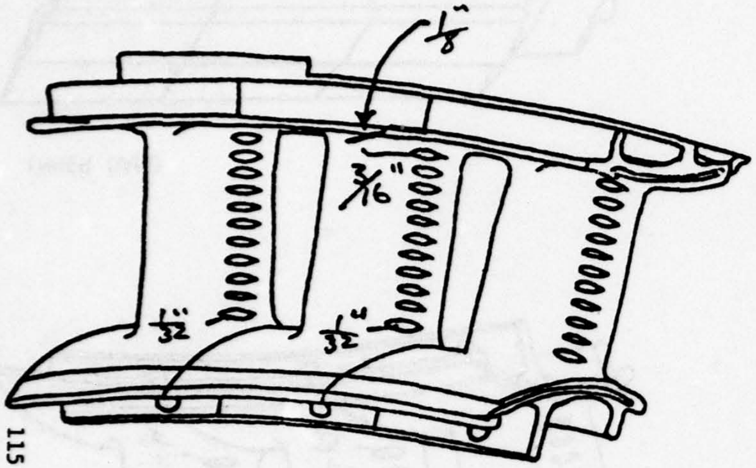

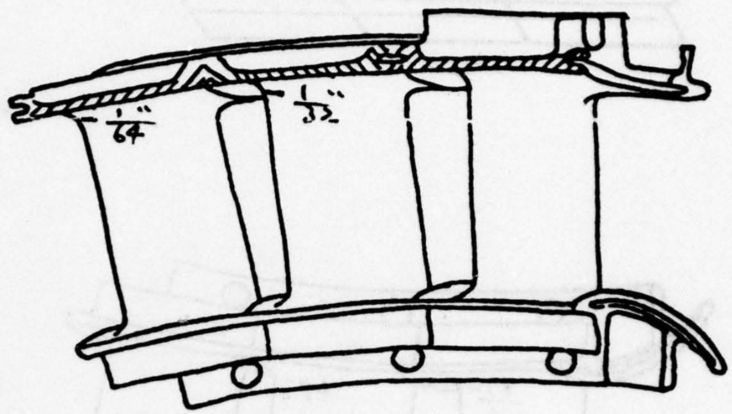

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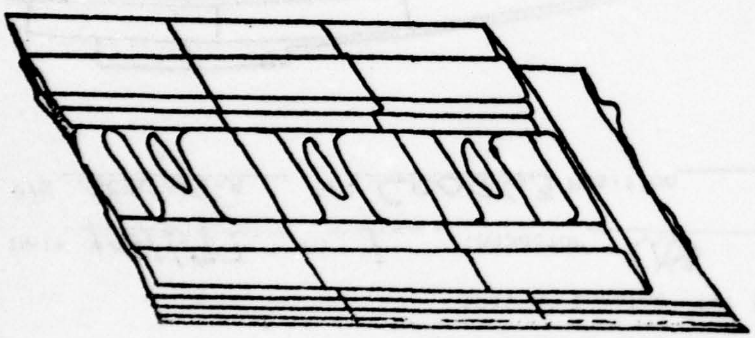

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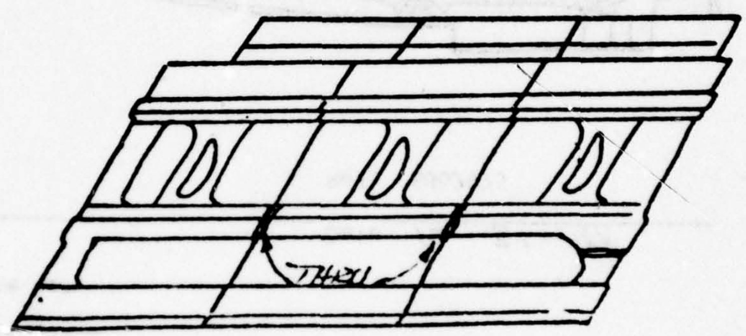

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 141677 TD 1 inspector [illegible] Date 1- 31-78

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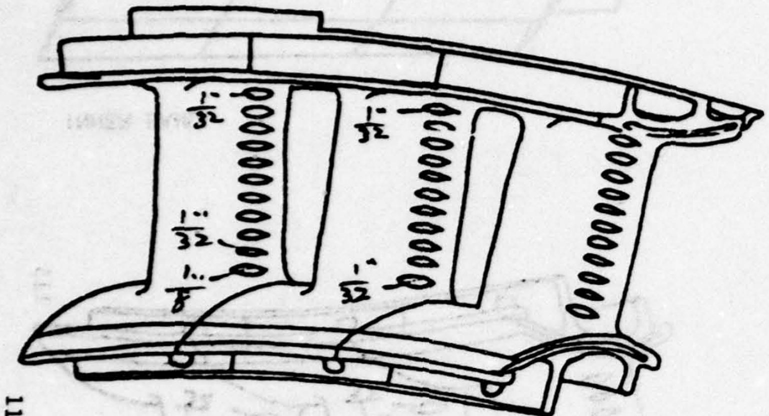

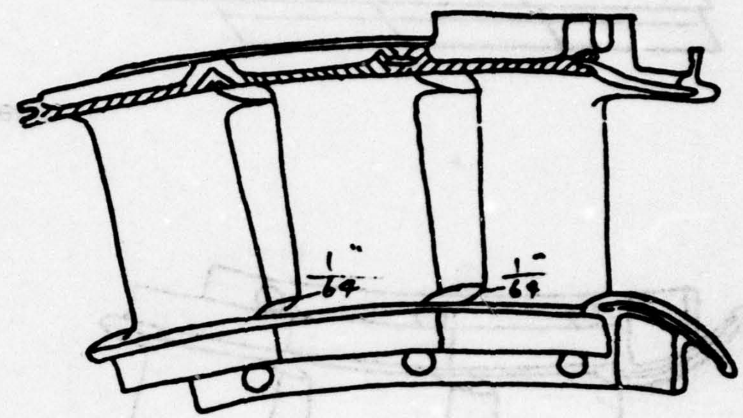

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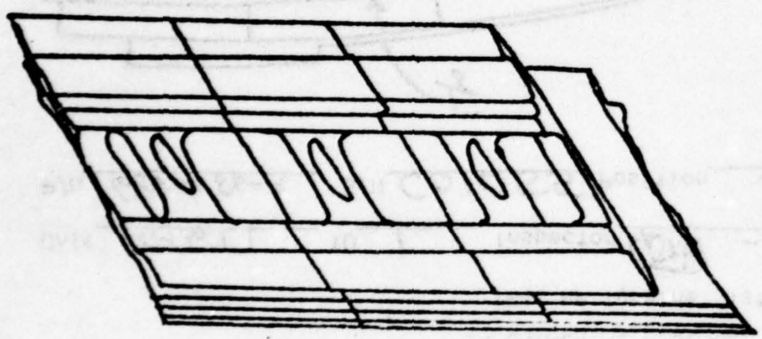

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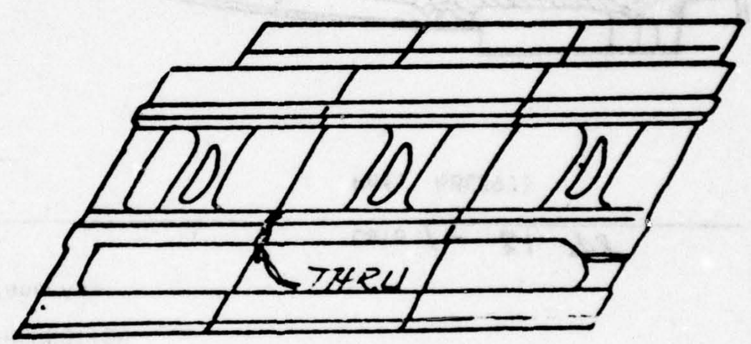

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 141677 TU 1 Inspector [illegible] Date 1- 31-78

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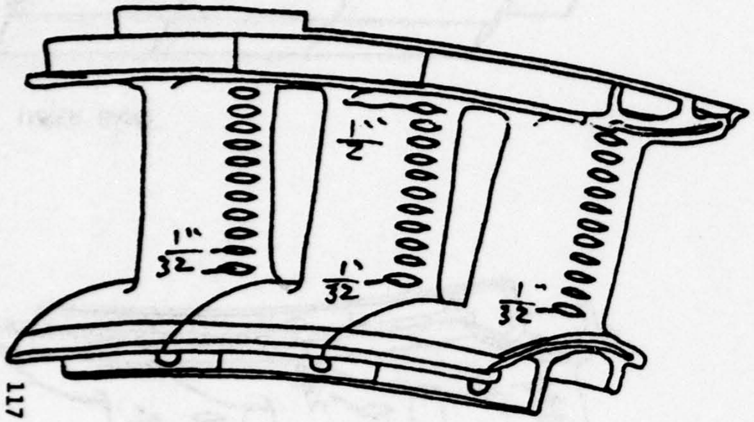

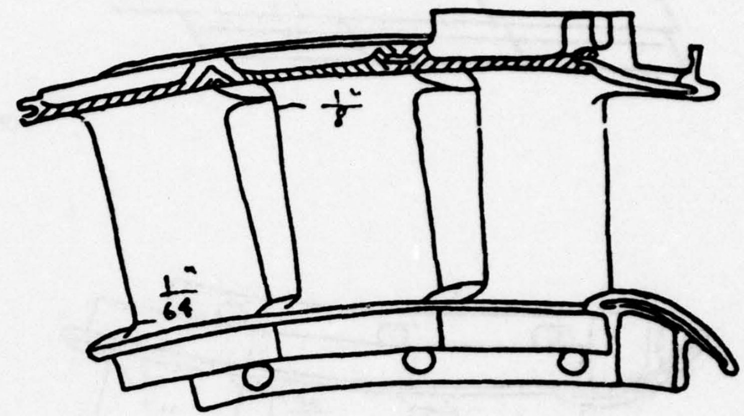

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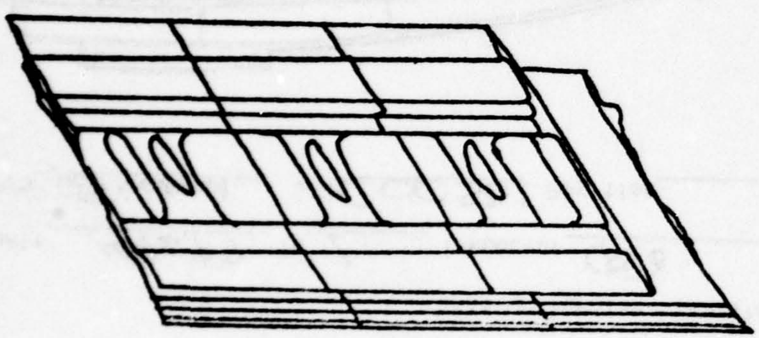

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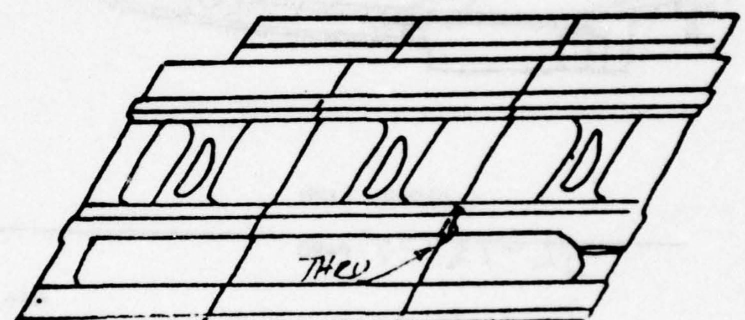

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 141677 TU 1 Inspector [illegible] Date 1-31-78

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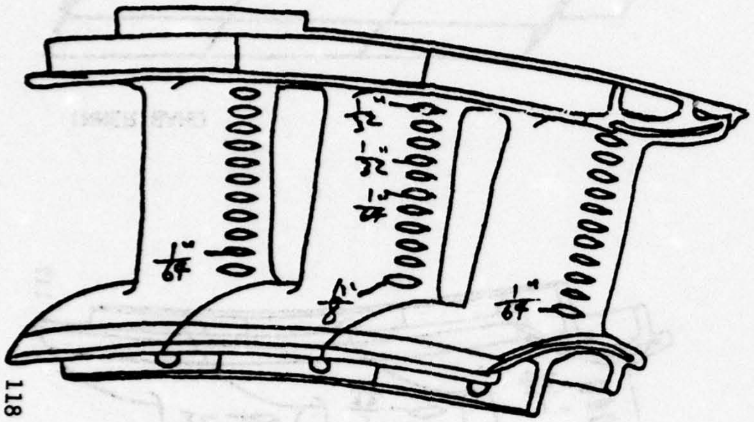

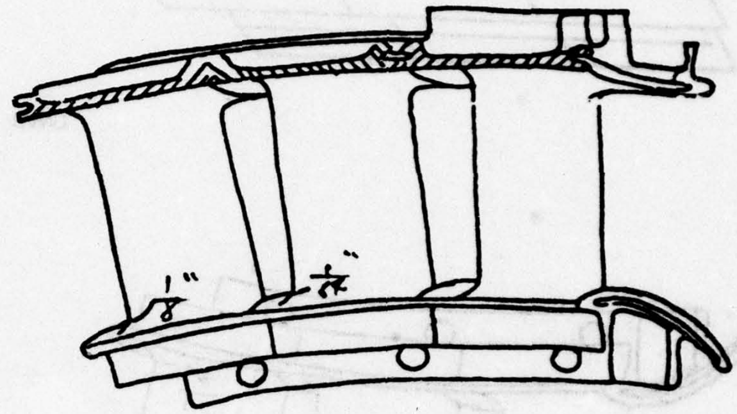

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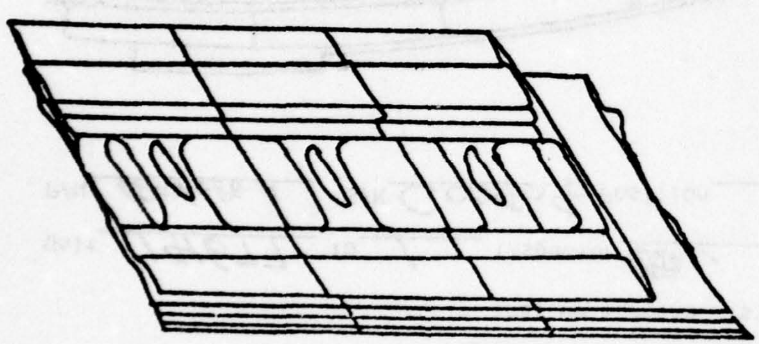

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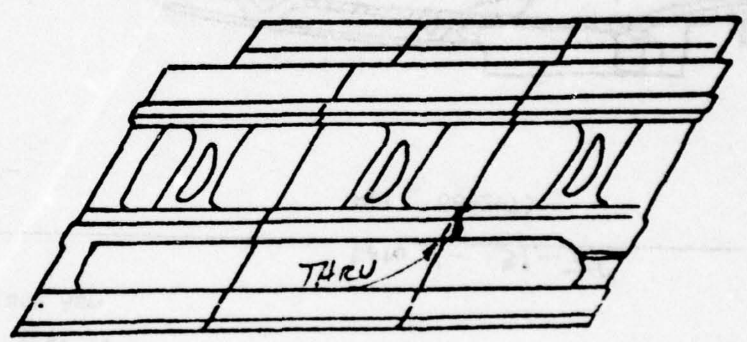
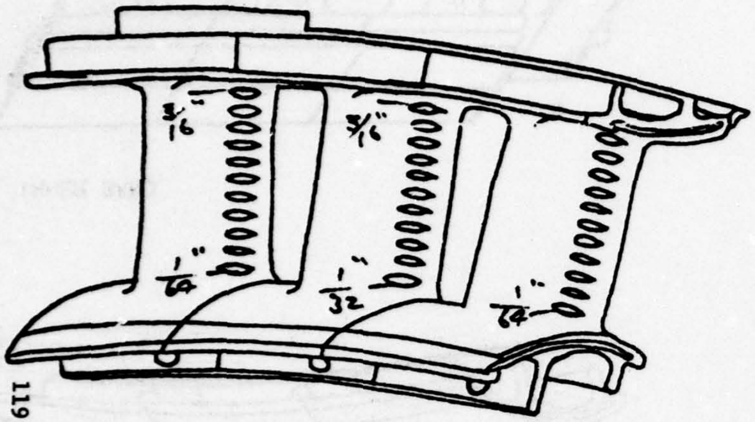


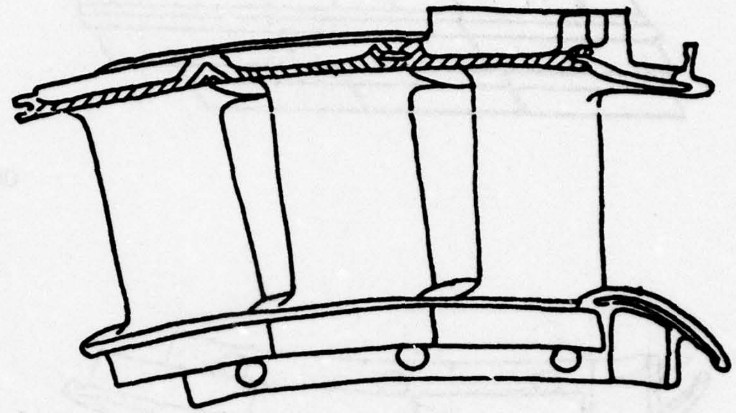
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 141677 TD 1 Inspector DAO Date 1-31-78

P/N 6894686A S/N C00633 Position ________ Ref: 6862973





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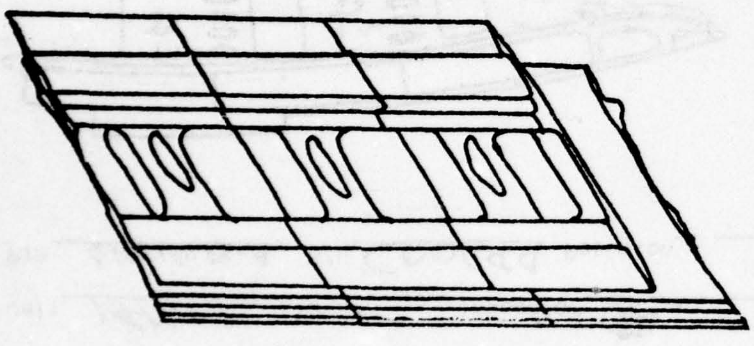

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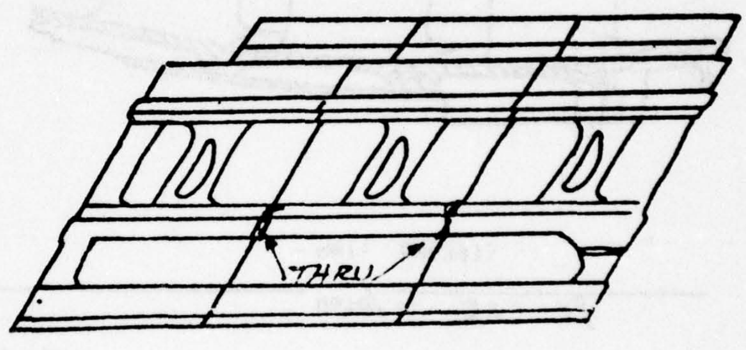

TF41 HP Turbine 1st Stage Vane Asm

Unit 141677 TU 1 Inspector [illegible] Date 7-31-78

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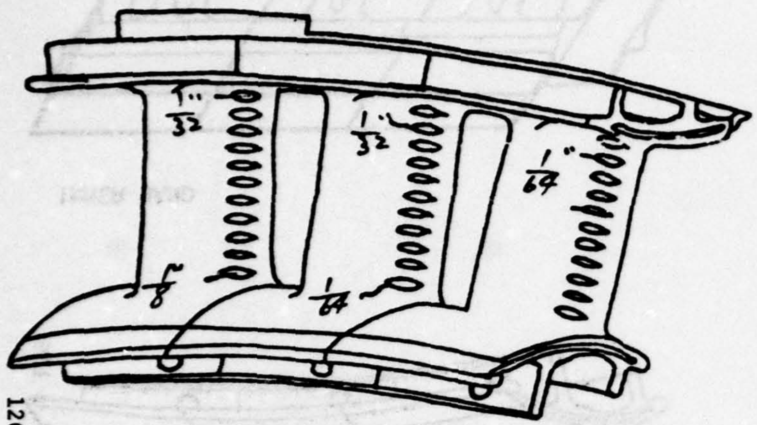

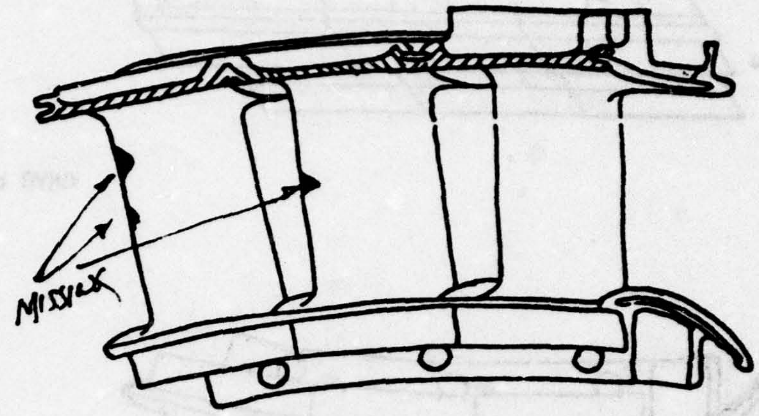

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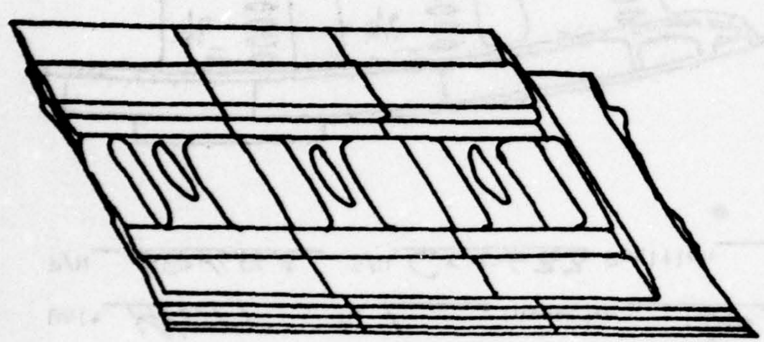

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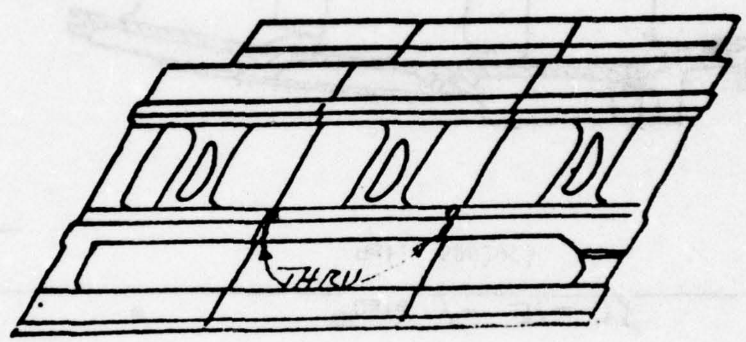


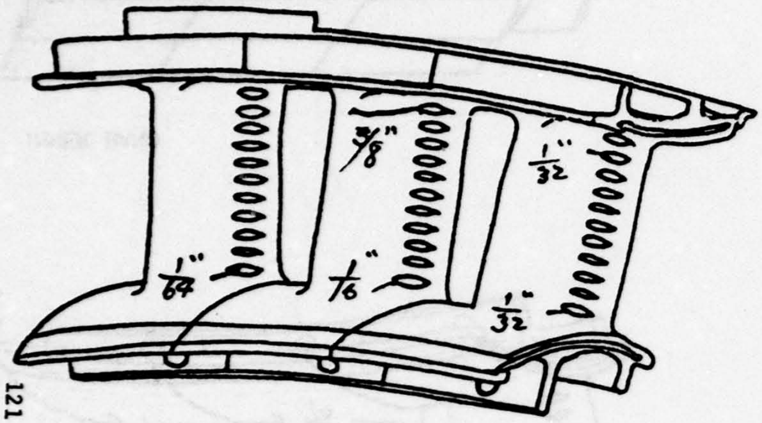
S/N TF41/Misc.
Page 30 of 32

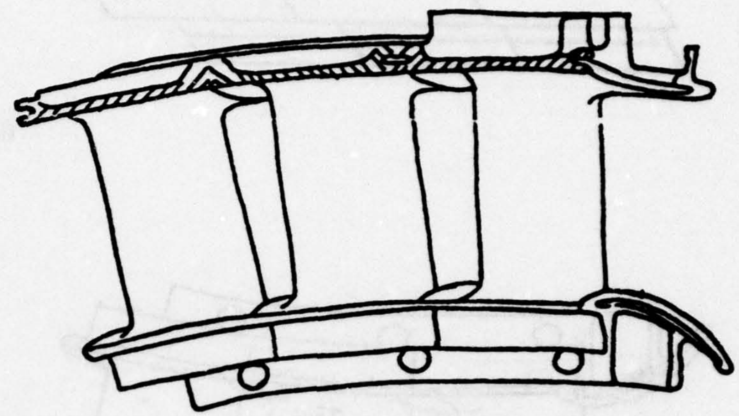
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 141677 TU 1 Inspector [illegible] Date 1-31-78

P/N 6894686-A S/N C01011 Position 3 Ref: 6862973





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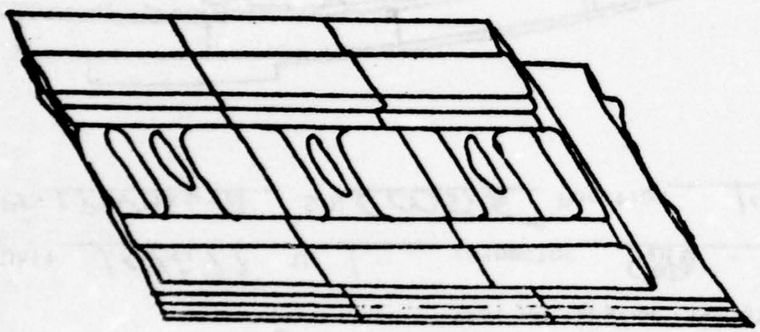

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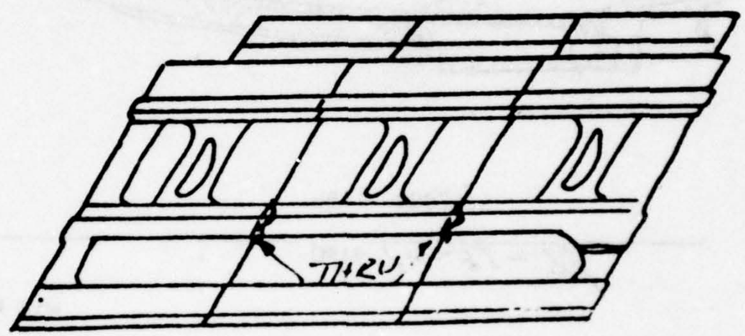

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 HP Turbine 1st Stage Vane Asm

Unit 141677 TD 1 Inspector [illegible] Date 1-31-76

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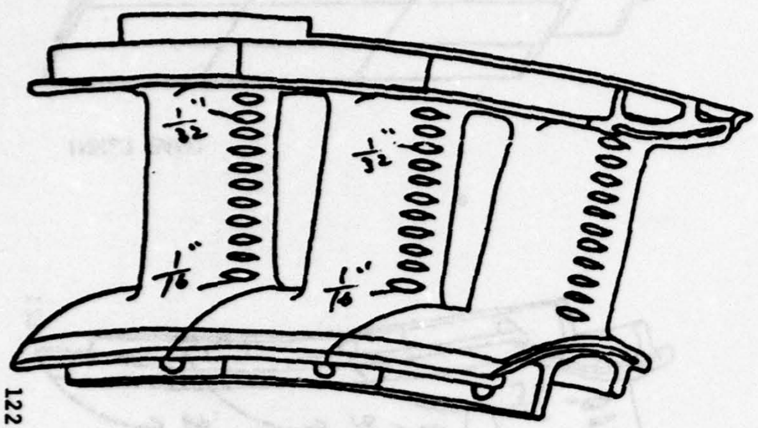

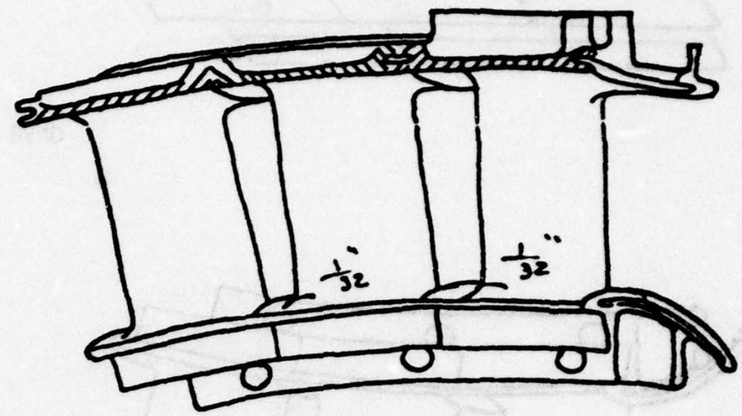

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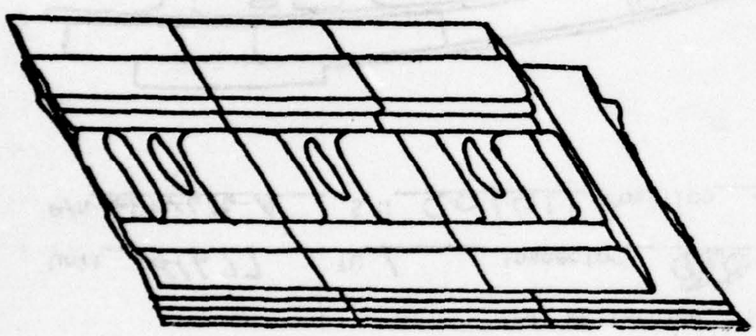

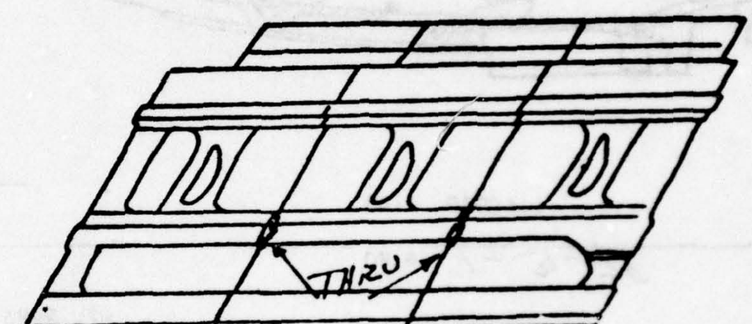

APPENDIX D

TEST PLAN

AIR FORCE AERO PROPULSION LABORATORY

20 July 1977

1. TITLE: ACCELERATED MISSION TEST (AMT) OF A TF41 WITH HPT-2 COOLED AIRFOIL BLADES

2. JON: 30661236

3. PROJECT ENGINEER: Robert J. May, Jr/TBA/54830

4. PROJECT TEAM: Kenneth N. Hopkins/TBC/55421
   Doretta Holland/TFIC/55636

5. CONFIGURATION: Engine Type TF41-A-1
   Serial Number: 141677
   Special Features -- Cooled Blades HPT-2
   IECMS Kit (on 2nd Build of Engine)

6. FACILITY: "3" Stand, AF Aero Propulsion Laboratory

7. FUEL/LUBES: Fuel MIL-T-5624, JP4
   Lube Oil: MIL-L-7808*

*See Hoover Smith, SFL, 54667 for a particular drum of MIL-L-7808 to be used for this test in 3-Stand. It will be Mobil 0-76-4.

8. TEST OBJECTIVES:

8.1 Establish durability characteristics of a TF41 with cooled HPT-2 airfoil blades.

8.2 Document overall engine performance deterioration and attempt to isolate major contributors to engine deterioration.

8.3 Investigate IECMS (In-Flight Engine Condition Monitoring System) diagnostic capability--engine build #2.

9. INSTALLATION:

9.1 Install engine in "3" stand according to standard TF41 procedures.

9.2 Instrument as specified in instrumentation section of this plan.

9.3 Install tailpipe and exhaust nozzle.

9.4 Install TF41 airmeter bellmouth and screen.

9.5 Connect power lever to automatic throttle and use standard throttle rigging of 15-18° at idle and 65-68° at intermediate power. Refer to TO 2J-TF41-6 for specific details.

9.6 Service engine with oil provided by SFL.

9.7 Take a 1-pint sample of oil (from oil drum) to SFL.

9.8 Check all instrumentation for current calibration data and recalibrate as necessary.

10. INSTRUMENTATION:

The following list describes the instrumentation requirements for the AMT cyclic test on engine S/N 141677.

10.1 Engine inlet temperature

10.2 Engine inlet pressure

10.3 Bellmouth static pressure

10.4 Low pressure rotor speed

10.5 High pressure rotor speed

10.6 Turbine outlet temperature

10.7 Fuel flow

10.8 Fuel inlet temperature

10.9 Low pressure and intermediate pressure compressor discharge pressure (dual probe)

10.10 Low pressure and intermediate pressure compressor discharge temperature (dual probe)

10.11 High pressure compressor discharge static pressure

10.12 High pressure compressor discharge temperature

10.13 Fuel manifold pressures, pilot and main

10.14 Low pressure turbine outlet pressure

10.15 Main oil ΔP

10.16 Engine main oil pressure

10.17 Low pressure cooling air outlet temperature

10.18 Engine vibration --

front compressor (vertical) - front flange top

rear compressor (vertical) - fuel manifold boss, top

turbine (near vertical) - LP turbine oil tube, bottom

10.19 IGV position

10.20 Power lever position

10.21 Engine oil inlet temperature

10.22 Engine thrust

10.23 Temperature limiter amplifier current

10.24 Junction box temperature

10.25 Exhaust gas temperature rake

10.26 Dry bulb temperature

10.27 Wet bulb temperature

10.28 Vapor pressure

11. <u>SPECIAL REQUIREMENTS</u>:

11.1 Continuous recording of the following parameters is required:

--engine inlet temperature

--turbine outlet temperature

--high pressure rotor speed

--low pressure rotor speed

--fuel flow

--temperature limiter amplifier current

12. <u>OPERATING LIMITS</u>:

The engine operating limits are those applicable to any TF41 engine and are spelled out in TO 2J-TF41-6. The operating limits should be coordinated with the TF41 test project team.

13. <u>STANDARD PROCEDURES</u>:

13.1 Record all start and stop data in log book, including reason for shutdown.

13.2 No operating limit adjustments shall be made during this test without the specific approval of the project engineer or other team member in his absence.

13.3 Take care to note in the engine log all incidents of the run such as overspeeds, overtemperature, leaks, vibra-

tions, irregular functioning of the engine, facility or instrumentation, smoking or sparking and describe any corrective action taken.

13.4 Once each working day, thoroughly inspect the engine and test equipment for leaks, loose bolts and fittings, visual cracks or impending failures, etc., including visual inspection of inlet and turbine. Complete other pre-start checklist requirements. Monitor the main oil filter and fuel filter pop-out switches. Make an entry in the engine log stating if the popout switches were in or out.

13.5 Daily record specific gravity of the fuel and reference temperature in the engine log. Also reset fuel flow recorder S.G. hourly if necessary.

13.6 Oil servicing shall be in accordance with current TF41-A-1 instructions. Maintain daily log of oil added and oil consumption during the entire test.

13.7 The low pressure compressor and intermediate pressure compressor pressure and temperature instrumentation should be removed during the cyclic testing portion of this test. This instrumentation should be installed only during power calibrations.

13.8 Full line of data should be recorded half way through the 6-minute flat at intermediate power near the end of each "A" cycle.

13.9 Power calibration should be run with the 7th and 11th stage bleeds blocked off.

13.10 The engine should be allowed to stabilize 5 minutes before recording power calibration data.

13.11 The desired tolerance on speed settings during the "automatic" portion of the test shall be $\pm$ 50 RPM N_H ($\pm$ 0.4%).

14. ENDURANCE TEST:

The engine will be trimmed and set up before delivery to AFAPL by Allison.

14.1 Engine Functional Check (every 50 hours). See TO 20-TF41-6, Para 10-35 and Table 10-4.

14.1.1 Check IGV ram closing schedule. Determine that the attached schedule is satisfied (IGV = +33° and 7°).

14.1.2 Check NL governor with pulldown tool according to TO 2J-TF41-6, Para 10-63.

14.1.3 Check T5.1 pulldown according to TO 2J-TF41-6, Para 10-66.

14.1.4 Check P3 limiter according to TO 2J-TF-41-6, Para 10-64.

14.1.5 Check NH governor according to TO 2J-TF41-6, Para 10-59, 10-60, 10-62.

14.1.6 Check ACU and DCU according to TO 2J-TF41-6, Para 10-70, 10-71, 10-72, 10-73.

14.2 High pressure rotor speed and power lever calibration (every 50 hours).

14.2.1 Stabilize 5 minutes at each NH speed and take a full line of data listed:

10,000 $\pm$ 100 RPM
10,500 $\pm$ 100 RPM
10,900 $\pm$ 100 RPM
11,300 $\pm$ 100 RPM
11,700 $\pm$ 100 RPM
12,100 $\pm$ 100 RPM
12,300 $\pm$ 100 RPM

14.2.2 Plot NH (RPM) versus power lever angle. Determine the power lever angle corresponding to the following speeds and provide this information to TFIC for generation of auto-throttle paper tape.

NH (RPM)	%RPM	PLA
10332	80	
10589	82	
10977	85	
11235	87	
11364	88	
11623	90	
12010	93	
12140	94	
12269	95	

14.3 Performance calibration (every 50 hours)

14.3.1 Blank off bleed ports

14.3.2 Install low pressure compressor and intermediate pressure compressor discharge instrumentation.

14.3.3 Stabilize for 5 minutes at the following levels of corrected thrust and take a full line of data.

8000 ± 200 lb
9000 ± 200 lb
10,000 ± 200 lb
11,000 ± 200 lb
12,000 ± 200 lb
13,000 ± 200 lb
14,000 ± 200 lb
intermediate

14.4 Scheduled Inspections

14.4.1 Perform engine borescope inspection of HP turbine vanes after every 100 endurance hours.

14.4.2 Standard field service inspections shall be made and documented throughout the test. Reference Allison Publication Nr 1F2, 1 March 1974, Section 7.

-- conduct 50-hour phase inspection in accordance with Section 7-7

-- conduct 100 hours phase inspection in accordance with Section 7-8

14.4.3 Take a 1-pint sample immediately after initial servicing and at approximately 25 test hour intervals thereafter. The containers will be furnished by SFL, Hoover Smith, 54667.

14.5 Cyclic testing

14.5.1 The actual test consists of running the engine through a specified number of test cycles, labeled the "A", "B", and "C" cycles. A detailed description of these cycles is included on the attached pages. The test consists of 15 blocks made up of 20 "A" cycles, 4 "B" cycles, and 1 "C" cycle each.

14.5.2 Remove high pressure compressor and intermediate pressure compressor instrumentation.

14.5.3 Enter "A" cycle into auto-throttle and run 20 cycles.

14.5.4 Enter "B" cycle into auto-throttle and run 4 cycles.

14.5.5 Enter "C" cycle into auto-throttle and run 1 cycle.

14.5.6 Repeat 14.5.5 - 14.5.7 fourteen (14) times performing the required inspections and calibrations, etc. as specified on the attached schedule.

Upon completion of 15 blocks of cyclic testing, remove the engine and return to Allison for a teardown inspection.

CYCLE A

FLIGHT OPERATION

TIME (Min:Sec) ELAPSED	AT	ACTION @ 66° CIT	P/L THROTTLE (CALIBRATION CURVE) FOR ALL CIT CONDITIONS
0:00	:30	Start Engine and accel to 55%	
0:30	2:00	Engine at Idle pwr	
2:30	:30	Accel to 90% N_H Dbl. datum on	
3:00	2:30	Accel to Intermediate Dbl Datum on	
5:30	1:00	Decel to 85% N_H, Dbl Datum Off	
6:30	2:00	Accel to Intermediate (100% N_H)	
8:30	:30	Decel to 90% N_H	
9:00	:15	Decel to 55% N_H	
9:15	:10	Accel to Intermediate	
9:25	:25	Decel to 93% N_H	
9:50	3:48	Accel to Intermediate, then Decel to 94% (19 Times). Each transient will take 6 sec.	
13:38	:12	Accel to Intermediate, transient to take 6 sec.	
13:50	:30	Decel to 88% N_H	
14:20	:08	Accel to Intermediate	
14:28	:15	Decel to 55% N_H	
14:43	:45	Accel to Intermediate	
15:28	:30	Decel to 88% N_H	
15:58	:08	Accel to Intermediate	
16:06	:15	Decel to 55% N_H	
16:21	:45	Accel to Intermediate	
17:06	:30	Decel to 88% N_H	
17:36	:08	Accel to Intermediate	
17:44	:07	Decel to 85% N_H	
17:51	:35	Accel to Intermediate	
18:26	:15	Decel to 90% N_H	
18:41	:08	Accel to Intermediate	
18:49	:07	Decel to 85% N_H	
18:56	:35	Accel to Intermediate	
19:31	:15	Decel to 90%	

CYCLE A

FLIGHT OPERATION

TIME (Min : Sec) ELAPSED	AT	ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
19:46	:08	Accel to Intermediate	
19:54	:07	Decel to 85% N_H	
20:01	:35	Accel to Intermediate	
20:36	:15	Decel to 90% N_H	
20:51	:08	Accel to Intermediate	
20:59	:07	Decel to 85% N_H	
21:06	:35	Accel to Intermediate	
21:41	:15	Decel to 90% N_H	
21:56	:08	Accel to Intermediate	
22:04	:15	Decel to 55% N_H	
22:19	:35	Accel to Intermediate	
22:54	:30	Decel to 88% N_H	
23:24	:08	Accel to Intermediate	
23:32	:15	Decel to 55% N_H	
23:47	:35	Accel to Intermediate	
24:22	:30	Decel to 88% N_H	
24:52	:08	Accel to Intermediate	
25:00	:15	Decel to 55% N_H	
25:15	:35	Accel to Intermediate	
25:50	1:00	Decel to 88% N_H	
26:50	:08	Accel to Intermediate	
26:58	:07	Decel to 85% N_H	
27:05	:35	Accel to Intermediate	
27:40	:15	Decel to 90% N_H	
27:55	:08	Accel to Intermediate	
28:03	:07	Decel to 85% N_H	

CYCLE A

TIME (Min : Sec)		ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
28:10	:30	Accel to Intermediate	
28:40	:15	Decel to 90% N_H	
28:55	:08	Accel to Intermediate	
29:03	:07	Decel to 85% N_H	
29:10	:30	Accel to Intermediate	
29:40	:25	Decel to 90% N_H	
30:05	:15	Decel to 55% N_H	
30:20	:10	Accel to Intermediate	
30:30	:05	Decel to 88% N_H	
30:35	6:00	Accel to Intermediate	
36:35	:15	Decel to 55% N_H	
36:50	1:10	Accel to Intermediate	
38:00	:05	Decel to 80% N_H	
38:05	:05	Accel to 87% N_H	
38:10	:05	Decel to 80% N_H	
38:15	:05	Accel to 90% N_H	
38:20	:15	Decel to 55% N_H	
38:35	:30	Accel to Intermediate	
39:05	:05	Decel to 82% N_H	
39:10	:05	Accel to 90% N_H	
39:15	:15	Decel to 55% N_H	
39:30	:30	Accel to Intermediate	
40:00	:05	Decel to 82% N_H	
40:05	:05	Accel to 90% N_H	
40:10	3:19	Decel to 55% N_H	
43:29		Shutdown engine	
45:29		Motor Engine on Starter	
47:59		Start Engine and Accel to Idle	
48:29		Engine at Idle Pwr Ready for Next Cycle	

TOTAL CYCLE ENDURANCE TIME: 43 Min. 29 Sec.

CYCLE B

FLIGHT LINE OPERATION

TIME (Min : Sec) ELAPSED	AT	ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
0:00	3:00	Engine at Idle Pwr	
3:00		Shutdown Engine	
5:00		Motor Engine on Starter	
7:30	:30	Start Engine and Accel to Idle Pwr	
8:00	3:00	Engine at Idle Pwr	
11:00		Shutdown Engine	
13:00		Motor Engine on Starter	
15:30	:30	Start Engine and Accel to Idle Pwr	
16:00	3:00	Engine at Idle Pwr	
19:00		Shutdown Engine	
21:00		Motor Engine on Starter	
23:30	:30	Start Engine and Accel to Idle Pwr	
24:00		Engine at Idle Pwr Ready for Next Cycle (A or C depending on schedule).	

TOTAL CYCLE ENDURANCE TIME 10 Min 30 Sec

CYCLE C
GROUND OPERATION
SFE TEST CYCLE SEQUENCE

TIME (Hr : Min : Sec) ELAPSED	AT	ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR A CIT CONDITIONS
0:00:00	3:00	Engine at Idle Pwr	
0:03:00	3:15	Accel to Intermediate (No DD)	
0:06:15	3:00	Decel to Idle Pwr	
0:09:15	3:15	Accel to Intermediate	
0:12:30	3:00	Decel to Idle Pwr	
0:15:30	3:15	Accel to Intermediate	
0:18:45	3:00	Decel to Idle	
0:21:45	3:15	Accel to Intermediate	
0:25:00	3:00	Decel to Idle	
0:28:00	3:15	Accel to Intermediate	
0:31:15	3:00	Decel to Idle	
0:34:15	3:15	Accel to Intermediate	
0:37:30	3:00	Decel to Idle	
0:40:30	3:00	Accel to 95%	
0:43:30	3:00	Decel to Idle	
0:46:30	3:00	Accel to 95%	
0:49:30	3:00	Decel to Idle	
0:52:30	3:00	Accel to 95%	
0:55:30	3:00	Decel to Idle	
0:58:30	3:00	Accel to 95%	
1:01:30	3:00	Decel to Idle	
1:04:30	3:00	Accel to 95%	
1:07:30	3:00	Decel to Idle	
1:10:30	3:00	Accel to 90%	
1:13:30	3:00	Decel to Idle	
1:16:30	3:00	Accel to 90%	

CYCLE C

GROUND OPERATION
SFE TEST CYCLE SEQUENCE

TIME (Hr : Min : Sec) ELAPSED	AT	ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
1:19:30	3:00	Decel to Idle	
1:22:30	3:00	Accel to 90%	
1:25:30	3:00	Decel to Idle	
1:28:30	3:00	Accel to 90%	
1:31:30	3:00	Decel to Idle	
1:34:30	3:15	Accel to Intermediate	
1:37:45	3:00	Decel to Idle	
1:40:45	3:15	Accel to Intermediate	
1:44:00	3:00	Decel to Idle	
1:47:00	3:15	Accel to Intermediate	
1:50:15	3:00	Decel to Idle	
1:53:15	3:15	Accel to Intermediate	
1:56:30	3:00	Decel to Idle	
1:59:30	3:00	Accel to Intermediate	
2:02:45	3:15	Decel to Idle	
2:05:45		Shutdown Engine	
2:07:45		Motor Engine on Starter	
2:09:45		Start and Accel to Idle Pwr	
2:10:15	:30	Engine at Idle Pwr Ready for Next Cycle	

TOTAL CYCLE ENDURANCE TIME 2 Hrs 6 Min 15 Sec

REVISION TO "3" STAND TEST PLAN (AMT S/N 141677)

Revision Number 1 25 Aug 1977

Additional Standard Procedures:

1. Monitor starter oil temperature during all motoring of the engine. The starter oil temperature should not exceed 300°F.

2. Allow the engine to stabilize 1 minute before taking data during the 6 minute "flat" at intermediate power during the"A" test cycle.

3. While the engine is stabilizing at intermediate power during the 6 minute "flat" read the fuel specific gravity from the chart and make the appropriate setting on both fuel flow recorders. (Offner and Brown).

4. Maintain a log of the number and type of test cycles run each day.

5. Rotor coast-down speeds need only be recorded for the final shutdown each day.

REVISION TO "3" STAND TEST PLAN (AMT S/N 141677)

Revision Number 2 7 Sept 1977

Additional Standard Procedures:

1.) Check the oil level 5 minutes after shutdown and add as required following either 2 "A" cycles, 4 "B" cycles, or 1 "C" cycle. Maintain accurate records of all oil added.

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